FERTILIZERS AND MANURES

by

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SECOND EDITION

Published by

W. B. ANDREWS

State College, Mississippi

1954

160502

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Preface to the First Edition

A vast amount of data have been collected on the response of crops and soils to fertilizers and manures during the past 100 years. In fact there are so many data and they occur in so many different publications that they are almost inaccessible to those who need to use them, except for a few individuals who have made a special study of the subject.

The author has reviewed much of the literature on the response of crops and soils to fertilizers and manures for use in teaching a course on the subject during the past ten years. During the past seventeen years he has conducted experiments on various problems connected with the use of fertilizers and manures which has also afforded the opportunity to review literature. This experience in teaching and research has afforded the opportunity to collect, organize, and interpret representative information on the response of crops and soils to fertilizers and manures.

The sources of the data presented in this study have been cited at the end of each chapter. The discussion is the author's interpretation of the data. Variations in the efficiency of certain practices, as shown by the data presented, suggest that the reader should study the data presented critically, and introduce new practices on a demonstration basis from which additional information on the efficiency of practices for maintaining or increasing crop yields may be obtained.

The discussion carries the significance of complex chemical equations without their inclusion. As the book is written the information is available to the average reader as well as those who are technically trained. Should the book be used as a text for advanced students, the instructor may supply chemical reactions as needed.

The author is deeply indebted to: research workers for the data presented; his students for objective criticism of the data as presented in class; farmers and agricultural works for their observations; to Professors T. T. Brackin and H. N. Drennon for reading the manuscript; to many who have supplied photographs and unpublished information; and to Miss Frances Drane, Mrs. Sybil Tapscott, and Mrs. Lorene Gholston for typing the manuscript.

<div align="right">W. B. Andrews</div>

State College, Mississippi
July 1, 1947

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Preface to the Second Edition

The first edition of The Response of Crops and Soils to Fertilizers and Manures was published in 1947. The need filled by this book is indicated by requirement for six printings.

Since 1947 the production of nitrogen by synthetic nitrogen plants has increased markedly, and the expansion program is still underway. In order to feed and clothe the increasing population the use of nitrogen will continue to increase rapidly though the increase may be interrupted occasionally because of economic conditions.

During the short space of time since 1947 the use of nitrogenous fertilizers has doubled in many old fertilizer consuming areas, and its use is becoming common place in areas which formerly used little. The use of nitrogenous fertilizers is encroaching on the areas which have previously used legumes in rotation to supply the little nitrogen used.

In the First Edition the chapter on The Use of Anhydrous Ammonia and Aqua Ammonia as Sources of Nitrogen was written on the basis of the limited amount of data collected by the Mississippi Agricultural Experiment Station during 1944–46, and farmers' experience in the use of anhydrous ammonia in Mississippi during March, April and May of 1947.

Since 1947 anhydrous ammonia has become a common source of nitrogen in most of the states in this country and in some foreign countries. Anhydrous ammonia is the leading source of nitrogen in several states. In addition solutions containing aqua ammonia and ammonium nitrate or urea, ammonium nitrate alone or a mixture of urea and ammonium nitrate are available in limited quantities for direct application to the soil.

The properties of the nitrogenous fertilizer solutions are different which introduces differences in their use and in the response to crops which may be anticipated from their use. It is the objective of the Second Edition of this book to bring the data up to date on the sources of nitrogen in liquid form.
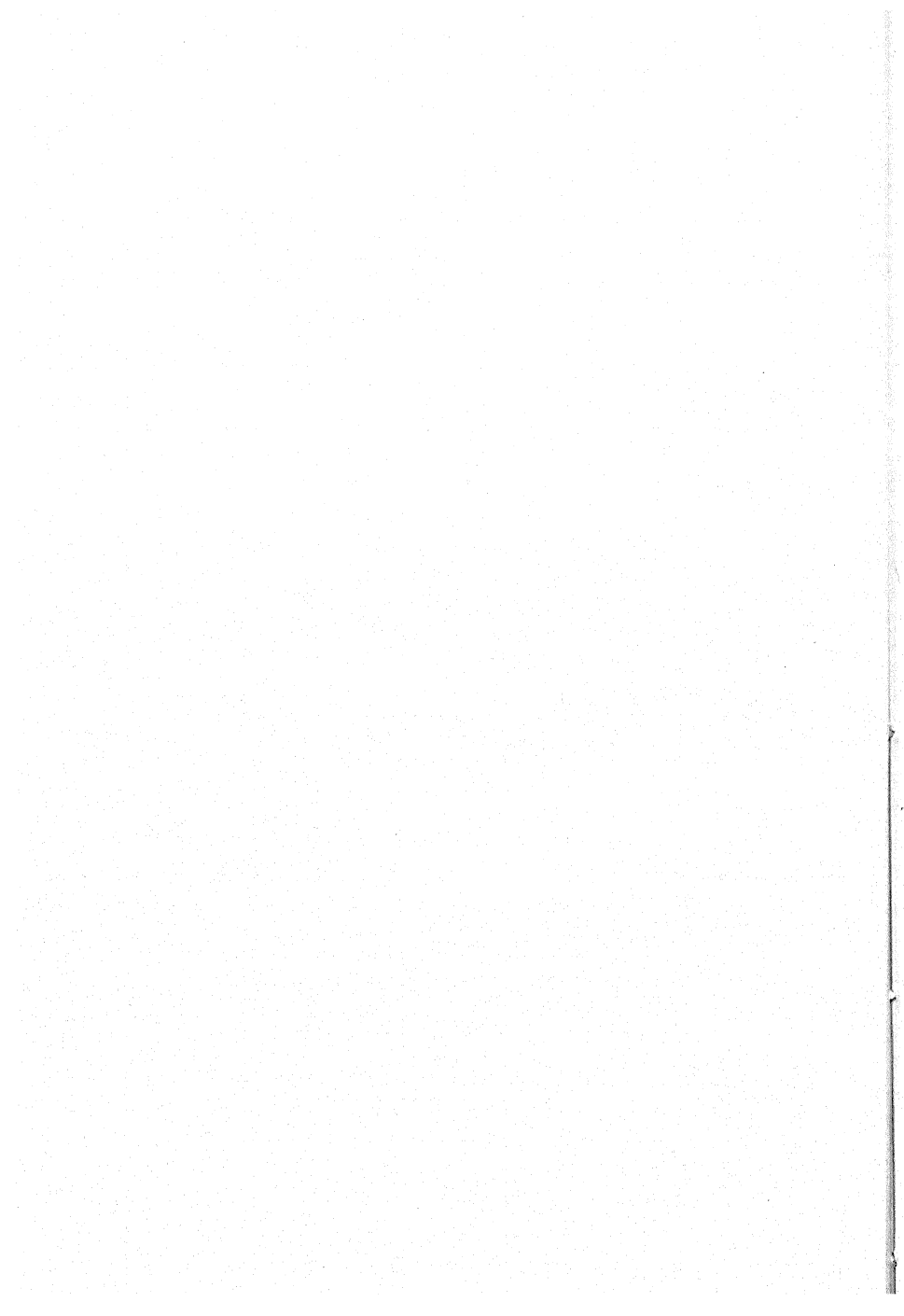
The author is deeply indebted to Mrs. J. T. Lamm for typing the manuscript and to H. P. Todd for helpful suggestions in its preparation.

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January 1954

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Introduction

Before fertilizers became widely used, people were searching for new land constantly. In the last 40 years the increase in the use of fertilizers has enabled farmers to grow crops continuously on land which would have been abandoned without their use. During this period the search for new land has been largely discontinued.

When people were searching for new land, crop yields were maintained or increased by animal manures, green manures, crop rotations, and lime. These practices did not supply sufficient plant nutrients to maintain crop yields on a large acreage; therefore, new lands were sought.

The use of commercial fertilizers has supplied sufficient plant nutrients to maintain or increase the yield of crops, and in so doing has reduced the search for new land.

The use of commercial fertilizers plus good management practices may enable the establishment of a permanent agriculture. In order to maintain a permanent agriculture in which commercial fertilizers play an important role, the difference between the cost of the fertilizers and the value of the crops produced must be sufficient to encourage their use, and their effect on the soil must be such that soil fertility is maintained.

There is a vast amount of information available on the response of crops to fertilizers and manures. However, the data occur in so many different publications that their usefulness has not been fully realized. The object of this study is (a) to accumulate representative information on the response of crops and soils to fertilizers and manures, (b) to so organize the data that they may be easily interpreted, and (c) to evaluate the data in terms of normal cost of fertilizers and prices of crops. The accumulation, organization, and evaluation of representative information on the response of crops and soils to fertilizers and manures should increase their usefulness.

The data presented in this study were obtained from carefully controlled experiments. The same treatment rarely produces identical results on two different soils. The fertility of similar soils on a given farm varies considerably because of previous fertilizer treatment and cropping history. The variations in soil fertility on one farm as well as that on different farms make it desirable for each farmer to study

carefully the fertilizer and cropping practices which may be used.

The reader is urged to examine the data presented in this book carefully; to read its contents critically; to look for the logic in the processes involved; to compare the conclusions drawn from the data with his own and with other farmers' experiences; and finally, to use his own conclusion based upon the data presented, other available information, and demonstrations conducted on the farm.

A brief summary of the data found in this study is presented below. The different chapters give the information on which the summary is based, and a discussion of the data presented.

A little over 100 years ago, Justus Von Liebig taught that plants use nutrients in simple combination, and that plant and animal material must be decomposed before the plant nutrients they contain become available to plants. Prior to this time people believed that plants used organic materials for food. At the present time organic materials are evaluated on the basis of the plant nutrients they contain; however, the low availability of their nitrogen is recognized.

The oldest experiments on the response of crops and soils to fertilizers and manures were started at Rothamsted, England, in 1843 by John B. Lawes and J. H. Gilbert. Many of the experiments started in 1843 are still underway. For 100 years of continuous wheat, good commercial fertilizers have maintained wheat yields equal to those obtained with animal manure, from which it is concluded that the crop producing value of manure is dependent on the plant nutrients supplied by it.

The high value of animal manure for increasing the yield of crops is generally recognized. The unusually high yields of crops produced where manure is applied is due to the high rates of application which contain very large quantities of plant nutrients. The nitrogen in manure is only about one-third as efficient for crop production as that in fertilizers; the phosphorus and potash in animal manure are as efficient or more efficient for crop production than these plant nutrients in fertilizers. Animal manure is high in potash as compared to the effective crop producing value of the nitrogen and phosphorus present.

The use of animal manure for crop production is a means of transferring plant nutrients from one field to another, and any consideration of this subject should be made in conjunction with a study of the effect of the removal of plant nutrients in hay crops on soil fertility. Under most systems of producing, handling and distributing animal manure, most of the plant nutrients contained in the feed are lost. In so far as animals can be fed and maintained on the land from which

hay crops are obtained, the high loss of plant nutrients is avoided.

Hay crops and other crops most of which are harvested deplete the soil of phosphorus and potash. It is significant that most rare element deficiencies occur where hay crops and other crops, most of which are harvested, are grown. The continuous growth of these crops without the use of high amounts of phosphorus and potash, and in many cases, rare elements, will deplete the fertility of most soils rapidly.

Farmers may choose either green manures or fertilizers to supply nitrogen to crops. The long-time trend in the cost of nitrogenous fertilizers has been down while green manure crops have become more expensive. Careful analysis of the data where green manure crops have been compared to nitrogenous fertilizers shows that the nitrogen supplied by green manure crops is generally more expensive than that supplied by nitrogenous fertilizers.

The feeding value of green manure crops is much greater than the cost of the nitrogen they supply to crops. The yield and feeding value of green manure crops is greater than the increase in yield and feeding value of another crop which results from turning them into the soil. It appears, therefore, that green manure crops should be planted for animals to eat, after which animal manures and crop residues should be turned into the soil for increasing crop yields.

As compared to commercial fertilizers, green manure crops increase labor or change the distribution of labor, and introduce additional risks. These factors are difficult to evaluate.

Only a small part of the nitrogen which is turned into the soil in leguminous green manure crops is recovered in the crops which follow. Eventually most of the nitrogen which is not recovered leaches out of the soil as nitrate of soda, nitrate of lime, nitrate of potash, and nitrate of magnesium; and, in addition to the nitrogen, these plant nutrients are lost. Continued success with leguminous green manure crops in humid climates is dependent upon the use of lime to replace that which is leached out by nitrogen.

The value of soil organic matter in the growth of crops is due primarily to the plant nutrients released when it decomposes. Organic matter is turned into the soil to decompose so that crops can get the nutrients released rather than for direct benefits that the organic matter might have. Soil organic matter decomposes rapidly in cultivated soils, which indirectly increases the yield of crops. Soil organic matter accumulates where land is given over to sod crops, and the plant nutrients contained in the organic matter also accumulate.

These nutrients become available to cultivated crops on decomposition of the accumulated organic matter when the land is brought into cultivation.

For corn production, 100 pounds of ammonium nitrate applied annually is equal to 24,000 pounds of soil organic matter.

From 1400 to 1730 the average yield of wheat in England was about 8 bushels per acre.[1] Over a 110-year period, 1730 to 1840, the use of crop rotations, leguminous green manure crops, and animal manure increased the yield to 20 bushels per acre. The use of commercial fertilizers began in 1840. By 1870 the yield of wheat had
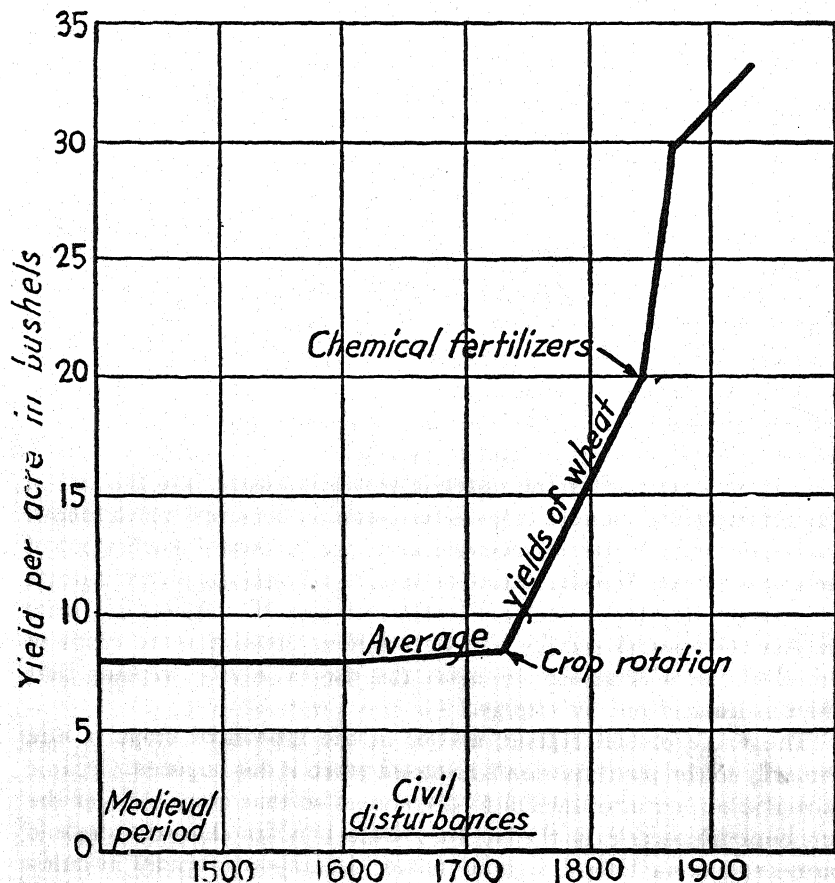

Fig. 1.—The relation of crop rotation and animal manures, and commercial fertilizer to the yield of wheat in England.

[1]Weir. Wilbert W. Soil Science. P. 18, 1936 J. B. Lippincott Company, Chicago.

increased to 30 bushels per acre, after which it has increased only slightly.

In the beginning, fertilizers were derived from bones, packing-house by-products, bird manure, and other by-products. Later, Chilean nitrate of soda, superphosphate from rock phosphate, by-product sulphate of ammonia, and potash from mines came into use. World War I introduced synthetic ammonia; World War II pyramided its production. The present capacity to produce fertilizers is far greater than the normal consumption. The development and perfection of the synthetic process for making ammonia from hydrogen from water and nitrogen from the air has been responsible for nitrogen becoming a cheap plant nutrient.

The sources of nitrogen most commonly used for crop production are nitrate of soda, ammonium nitrate, sulphate of ammonia, uramon (urea) and cyanamid. The soda in nitrate of soda increases the yield of many crops, thus enhancing its value as a fertilizer. Ammonium nitrate, sulphate of ammonia, and uramon are good sources of nitrogen and they have wide adaptability. Cyanamid is not as widely adapted as other sources of nitrogen because its nitrogen is not utilized by plants before it is changed to ammonia, a transformation that some-times takes place slowly.

The different sources of nitrogen have widely different effects on the available plant nutrients in the soil. Cyanamid increases the lime content of the soil; nitrate of soda maintains the lime content of the soil or causes a slight increase; ammonium nitrate and uramon decrease the lime content of the soil; and sulphate of ammonia takes more lime out of the soil than any source of nitrogen commonly used. Sources of nitrogen which maintain or increase the lime content of the soil exert a beneficial effect on the available phosphorus and potash, and sources which reduce the available lime in the soil decrease the available phosphorus and potash.

The use of lime on strongly acid soils reduces the amount of phosphate and potash required for crop production. The use of lime enables the growth of plants which are not adapted to strongly acid soils. It might also be pointed out that the use of too much lime reduces the availability of potash and boron.

Superphosphate is the primary source of phosphorous used for crop production. Only a very small per cent of the phosphorus applied is recovered in crops. The low recovery of phosphorus applied to soils is due to its conversion into forms not available to plants. The supplies

of rock phosphate in this country for making superphosphate are sufficient to last 2,000 years at the present rate of consumption.

Muriate of potash is the primary source of potash used for crop production. The known supplies of easily minable potash in this country are sufficient to last for about 100 years at the present rate of consumption. The known deposits of potash in this country should not be depleted to the point that potash will not be available during wars. It is doubtful if the known potash resources contain more than enough easily minable potash to insure a sufficient supply during wars, which means that mining of American potash during peace time may not be sound national economy. Explorations for locating additional supplies of potash should be continued.

Mixed fertilizers containing two or more of the elements, nitrogen, phosphorus and potash are widely used in the United States. Mixing fertilizers by industry relieves the farmer of the necessity of mixing them on the farm, but increases the cost of the plant nutrients. The plant nutrients in high analysis fertilizers are usually cheaper than those in the low analysis fertilizers. At the beginning of the fertilizer industry the ingredients which went into mixed fertilizers were low in plant nutrients. At the present time many of the ingredients which go into mixed fertilizers are high in plant nutrients. Filler may be used in high analysis fertilizers to make fertilizers of lower analysis. It is anticipated that high analysis fertilizers which contain the same materials except filler will come into more general use, and eventually largely replace low analysis fertilizers.

Buying fertilizers wisely is dependent upon complete knowledge of the crop-producing values of the different materials which may be used, and their long-time effect on soil fertility. The factors that influence the profit which may be obtained from the investment of a given amount of money in fertilizers are: (a) cost, (b) source of nitrogen, (c) source of phosphorus, (d) degree of ammoniation of superphosphate, (e) source of potash, (f) time of application of nitrogen, (g) effect of the fertilizer on the long-time fertility of the soil and others. These factors may be responsible for a farmer's getting from about 4,000 to 9,000 pounds of seed cotton from $100 invested in fertilizers.

The most efficient placement of fertilizers for row crops is in bands. Where 600 pounds of ordinary analysis fertilizers or less is applied before bedding land for planting, the fertilizer band may be placed directly under the place where the seed are to be planted. At planting time complete fertilizers should be placed to the side of and below the seed. Where very large quantities of fertilizer are used, they should be

placed to the side of and below the seed. Basic slag and lime should be placed in contact with or directly below legume seed where the rate of application is low. Superphosphate and muriate of potash should not be placed in contact with the seed.

The nutrients needed by plants are also required by animals. Feeds which are high in plant nutrients produce more animal products and are more palatable than feeds low in nutrients. The application of lime and phosphate to pastures and other feed crops on soils low in these nutrients increases the yield and feeding value of the crops produced. A deficiency of either of these plant nutrients in pastures may be recognized by animals grazing fertilized strips more closely. The effect of the quality of forage and pasture crops on the success of livestock enterprises is demonstrated by the suitability of different soil areas for livestock production.

Well fertilized ponds produce as much as 600 pounds of fish per acre, where unfertilized ponds produce no more than 100 to 150 pounds per acre. The application of fertilizers to ponds increases the microscopic water plants on which water insects feed, and the production of insects is increased in proportion to the increase in yield of microscopic water plants. The greater production of water insects increases the food for insect-eating fish and a larger production of these fish is obtained. The increase in the production of insect-eating fish on which fish-eating fish live likewise increases the production of fish-eating fish. Fertilizers may be used to control under-water weeds.

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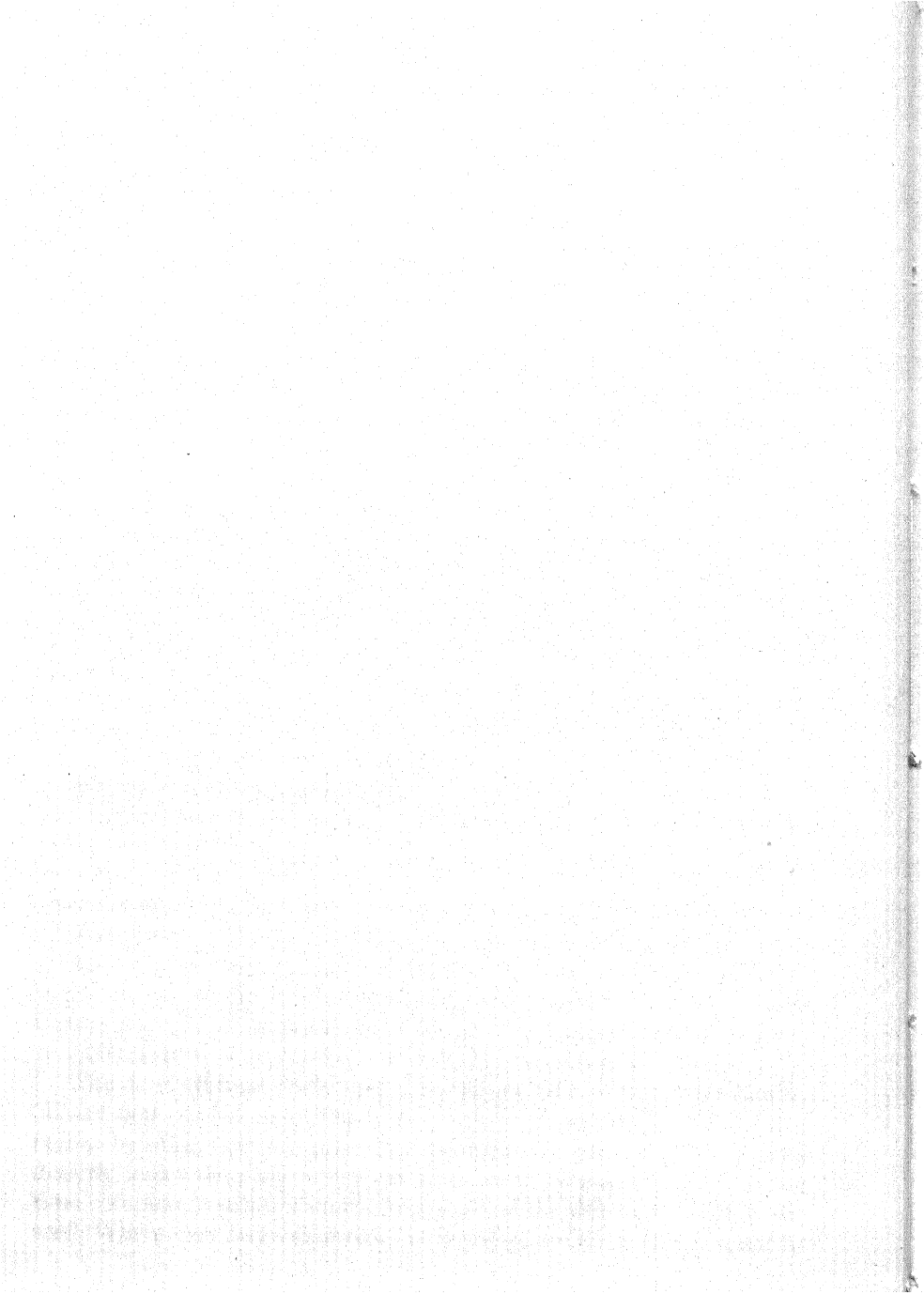
Crop Response to Sources of Nitrogen

Nitrogen is the most deficient element in soils of humid climates.

Prior to 100 years ago farmers used crop rotations, green manures, and other organic materials to supply nitrogen to crops. At the present time they have available nitrate of soda from Chile, sulphate of ammonia from coal, and the synthetic sources of nitrogen which are ammonium nitrate, cyanamid, uramon (urea), anhydrous ammonia, aqua ammonia, and a few other sources which are used to only a limited extent.

Cyanamid is also given consideration in a special chapter due to the properties of this source of nitrogen. Anhydrous ammonia and aqua ammonia are treated in a separate chapter due to their physical properties being entirely different to those of other sources of nitrogen. These sources of nitrogen were first used by farmers on a large scale this year, 1947. Equipment for the application of anhydrous ammonia and aqua ammonia is also discussed in the special chapter on these two sources of nitrogen.

The oldest nitrogen sources test in the United States has been conducted by the Pennsylvania Agricultural Experiment Station (16).[1] It was started in 1882. The total yields of corn, oats, wheat, and hay obtained with complete fertilizers are reported in Table 1. There was little difference in the yields of crops for the first 16 years where nitrate of soda, sulphate of ammonia, and dried blood were used. The yields on the plots where sulphate of ammonia and dried blood were used decreased after 16 years.

The yield obtained where nitrate of soda was applied was maintained over the 49-year period, and the addition of lime to this plot increased crop yields only slightly.

The yield of crops obtained where sulphate of ammonia was applied declined rapidly after 16 years, and after 40 years it was approximately 30% of that obtained at the beginning of the test. Liming the soil

[1]Numbers in parenthesis refer to the source of information, page 38.

which received sulphate of ammonia for 40 years overcame the harmful effects of the sulphate of ammonia, which suggests that sulphate of ammonia reduced the lime content of the soil.

The yield of crops obtained where dried blood was applied declined gradually throughout the 49-year period. The decline was slow but clearly evident. The decline in yield with dried blood was very much smaller than that obtained with sulphate of ammonia. The use of lime on this plot after 40 years increased the yield of crops to the original level, which suggests that the decline in the yield was due to the loss of lime where dried blood was applied.

Table 1.—The Response of Corn, Oats, Wheat, and Hay in Rotation to Sources of Nitrogen.

Rotation Periods	Nitrate of soda	Sulphate of ammonia	Dried blood
Yield of corn, oats, wheat and hay—pounds per acre per rotation			
1882-1889 unlimed	18,512	20,034	18,278
1890-1897 unlimed	19,413	19,035	19,410
1898-1905 unlimed	17,661	15,905	16,721
1906-1913 unlimed	19,276	14,892	18,656
1914-1921 unlimed	18,297	11,876	16,673
1922-1930 unlimed	16,262	6,081	13,698
1922-1930 limed	18,786	19,735	18,441

The effect of sulphate of ammonia, stable manure, and nitrate of soda on the yield of wheat and barley grown continuously at Woburn, England, (20) is shown by the data reported in Table 2. The yield of wheat produced where sulphate of ammonia was applied was maintained nearly equal to that obtained where nitrate of soda was applied for 30 years, but dropped off considerably after that time. On the sulphate of ammonia plot the yield of barley was maintained almost equal to that on the nitrate of soda plot for 20 years, and it decreased to a crop failure in 30 years. The yield of wheat and barley declined over the period where either nitrate of soda or manure was used.

The response of cotton to sources of nitrogen in short-time tests is shown by data in Table 3 from 222 experiments conducted in Alabama (24). The duration of the tests was too short for the sources of nitrogen to have had a marked influence on the soil, and the results are, therefore, a measure of the response of cotton to different forms of nitrogen, and to the associated elements, which were sodium, calcium, and sulphur.

Table 2.—THE LONG-TIME RESPONSE OF WHEAT AND BARLEY TO
SOURCES OF NITROGEN.

Periods	Farm yard manure	Sulphate of ammonia[1]	Nitrate of soda[1]
Yield—wheat (bushels per acre)			
1st. 20 years, 1877-1896	27.3	30.2	31.3
3rd. 10 years, 1897-1906	24.0	24.4	23.6
4th. 10 years, 1907-1916	19.6	15.8	17.5
8 years, 1917-1924	20.8	10.6	18.7
Yield—barley (bushels per acre)			
1st. 20 years, 1877-1896	39.4	39.1	43.5
3rd. 10 years, 1897-1906	36.6	7.2	35.3
4th. 10 years, 1907-1916	30.9	crop failed	19.8
8 years, 1917-1924	27.2	crop failed	18.1

[1] Phosphate and potash were also used.

The average increase in yield of seed cotton for the 222 experiments
was nitrate of soda 337, sulphate of ammonia 301, ammo-phos A and
nitrate of soda 275, leunasalpeter 277, urea 291, and cottonseed meal
192 pounds per acre. Since there were 222 experiments, the data should
be quite reliable.

Nitrate of soda was superior to all other sources of nitrogen, except
on Hartselle, Cecil and Greenville soils, and sulphate of ammonia was
superior to a combination of ammo-phos A and nitrate of soda, urea,
and cottonseed meal. Cottonseed meal was a poor source of nitrogen.

Table 3.—AVERAGE INCREASE IN YIELD OF SEED COTTON ON VARIOUS SOIL REGIONS FROM DIFFERENT
SOURCES OF NITROGEN—1927-1931.

Plot	Source of nitrogen·	Soil group and number of tests								
		Clarkes-ville	De-catur	Hols-ton	Hart-selle	Cecil	Oktib-beha	Green-ville	Nor-folk	Aver-age
		10	32	21	36	17	15	34	57	222
		Increase in yield—pounds of seed cotton per acre								
3	Nitrate of soda......	312	284	417	365	363	221	374	320	337
4	Sulphate of ammonia.	270	249	336	364	361	158	362	262	301
7	Ammo-phos A[2], and nitrate of soda	215	272	310	319	293	225	341	209	275
8	Leunasalpeter.......	247	256	291	287	339	144	333	261	277
9	Urea..............	226	284	339	318	317	175	331	265	291
10	Cottonseed meal.....	220	139	363	175	226	21	235	205	192

All plots received 64 pounds of phosphoric acid and 25 pounds of potash, and all nitrogen plots
received 30 pounds of nitrogen per acre.
[2] One-half of the nitrogen from ammo-phos A and one-half from nitrate of soda.

Nitrate of soda produced 36 pounds of seed cotton per acre more than did sulphate of ammonia, which, at 5 cents per pound, has a value of $1.80. In 1941 the cost of 30 pounds of nitrogen was about $3.37 in nitrate of soda and $2.70 in sulphate of ammonia. The thirty pounds of nitrogen cost $0.67 more in nitrate of soda than in sulphate of ammonia and made $1.13 more profit. On 13 1/3 acres at the rate of 30 pounds of nitrogen per acre, as was used in these tests, 2500 pounds of nitrate of soda, costing about $45.00, produced 480 pounds of seed cotton, valued at $24.00, more than was produced by 2000 pounds of sulphate of ammonia, costing $36.00 (1941 prices). Sulphate of ammonia was superior to the sources of nitrogen used in these tests, other than nitrate of soda.

Table 4.—THE RESPONSE OF OATS AND COTTON TO SOURCES OF NITROGEN.

Plot	Source of nitrogen[1]	Oat yield average 7 years	Cotton yield average 5 years
		Bushels	*Pounds*
1, 5	Nitrate of soda..........	24.9	819
2, 6	Cyanamid..............	20.9	876
3, 7	No nitrogen............	6.2	347
4, 8	Sulphate of ammonia....	18.7	445

[1]All plots received 160 pounds of superphosphate, 100 pounds of kainit, and 22.5 pounds of nitrogen per acre.

At Auburn, Alabama, (24) a test was started in 1911 to compare the use of nitrate of soda, cyanamid, and sulphate of ammonia for crop production. The average yields of 7 crops of oats (1925–1932) and 5 crops of cotton (1920–1924) are reported in Table 4. The increase in yield of cotton produced where sulphate of ammonia was applied was very low, even though only 202 pounds of nitrogen had been applied previous to the time cotton was first planted. The average increase in yield of seed cotton for sulphate of ammonia was 98 pounds per acre, while nitrate of soda and cyanamid increased the yield 462 and 529 pounds per acre, respectively. Similar results were obtained with oats, except nitrate of soda produced higher yields than cyanamid.

The response of cotton to nitrate of soda and sulphate of ammonia on limed and unlimed soil is shown by data (24) in Table 5. On the limed soil sulphate of ammonia was equal to nitrate of soda for cotton production at the low rate of application. At the high nitrogen rate sulphate of ammonia was superior to nitrate of soda on limed soil; however, erosion damaged the nitrate of soda plot in 1930, a fact suggesting that erosion may have been responsible for the difference

FIG. 1.—The poor stand of stunted cotton on the left was obtained after 8 years' treatment with sulphate of ammonia on unlimed soil. Nitrate of soda was used on the right. The center row received no nitrogen (24). (Courtesy Alabama Agricultural Experiment Station.)

in favor of sulphate of ammonia at the high rate. The note at the bottom of the table indicates that there was only one plot of each treatment, which suggests that the data should be used cautiously. On the

Table 5.—THE REACTION OF THE SOIL AND YIELD OF SEED COTTON WITH DIFFERENT SOURCES OF NITROGEN ON CECIL SANDY LOAM.

Plot	Treatment[1] (pounds per acre)	1932	1925	1926	1927	1928	1929	1930	1931	7-year average	
										Yield	Increase for lime
	Limed[2]	pH				Yield—pounds of seed cotton per acre					
1[3]	400 nitrate of soda	5.8	825	1,375	1,159	1,333	1,137	1,020[3]	1,129	1,139	32
2	300 Sulphate of ammonia	4.5	796	1,445	1,232	1,408	1,181	1,221	1,294	1,225	335
3	No nitrogen	5.3	766	992	710	620	781	799	669	762	50
4	200 nitrate of soda	5.8	792	1,333	1,116	1,036	1,100	1,143	1,140	1,094	54
5	150 sulphate of ammonia	5.1	783	1,329	1,126	946	1,080	1,259	1,134	1,093	165
	Unlimed					Yield—pounds of seed cotton per acre					
6	400 nitrate of soda	5.4	671	1,214	1,130	1,118	1,173	1,229	1,217	1,107	..
7	300 sulphate of ammonia	4.2	669	957	824	854	1,014	805	1,107	890	..
8	No nitrogen	5.0	658	834	594	543	671	950	733	712	..
9	200 nitrate of soda	5.3	713	1,157	1,005	825	1,100	1,240	1,241	1,040	..
10	150 sulphate of ammonia	4.8	708	1,014	807	862	904	1,062	1,137	928	..

[1]All plots received 600 and 100 pounds of superphosphate and muriate of potash per acre, respectively.
[2]Limestone was applied in 1914 at the rate of 5,300 pounds per acre.
[3]Plot No. 1 was damaged by erosion in 1930.

unlimed soil, nitrate of soda made 112 and 217 pounds more seed cotton at the low and high rates, respectively, than did sulphate of ammonia. The use of lime had practically no effect on the yield of cotton where nitrate of soda was used, and it increased the yield where sulphate of ammonia was used to that obtained where nitrate of soda was applied. Since nitrate of soda is generally superior to other sources of nitrogen for cotton production, data on a large number of tests would be required in order to reach a conclusion that other sources of nitrogen are equal to nitrate of soda for cotton production on limed soil.

Table 6.—The Response of Cotton to Dolomite with Nitrate of Soda and Sulphate of Ammonia as Sources of Nitrogen.

Nitrogen Fertilizer*	Dolomitic limestone*	Yield of seed cotton per acre		Increase in yield from dolomitic limestone	
		Without lime	With dolomitic lime		
Sulphate of ammonia		Pounds	Pounds	Pounds	Percent
None	200	776	741	−35	−5
150	200	1,054	1,149	95	9
300	400	1,103	1,257	154	11
600	800	.568	1,307	739	130
1,200	1,600	....	1,206	....	....
Nitrate of soda					
None	200	776	741	−35	−5
200	200	1,164	1,088	−76	−7
400	400	1,294	1,246	−48	−4
800	800	1,226	1,124	−102	−8
1,600	1,600	1,212	1,035	−177	−15

*Pounds per acre.

The effect of rate of application of nitrate of soda, sulphate of ammonia, and dolomitic limestone on the yield of cotton in Georgia (13) is shown by data in Table 6. Without lime the use of 150 or 300 pounds of sulphate of ammonia per acre produced good increases in yield of cotton; 600 pounds cut the yield in half; and no cotton was produced with 1,200 pounds per acre. The use of dolomite in the fertilizer increased the yield significantly with all rates of sulphate of ammonia, and largely overcame the harmful effects of high rates of sulphate of ammonia. In contrast to the reduced yields with high amounts of sulphate of ammonia, the yield of seed cotton was not reduced significantly by as much as 1,600 pounds of nitrate of soda per acre.

Dolomitic limestone increased the yield 95 to 739 pounds of seed cotton per acre with different rates of sulphate of ammonia, and re-
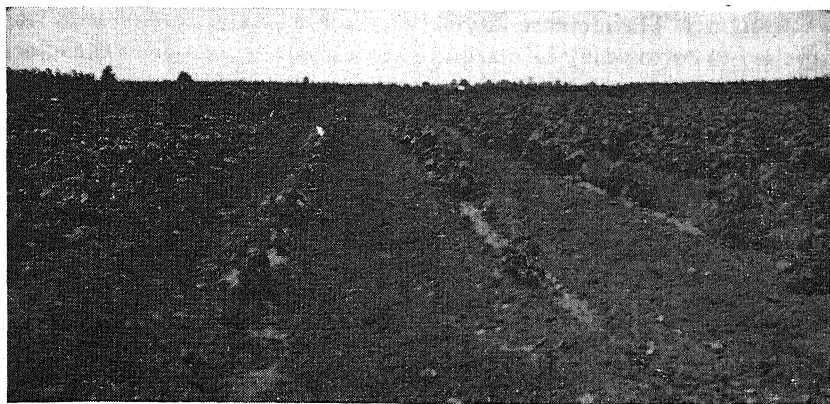
FIG. 2.—Cotton fertilized with complete acid fertilizer plus limestone without sulphur (24). (Courtesy Alabama Agricultural Experiment Station.)

duced the yield 76 to 177 pounds of seed cotton per acre with different rates of nitrate of soda. The increase in yield for dolomitic limestone with sulphate of ammonia was due to the neutralization of the acid effect of the sulphate of ammonia. The reduction in the yield of seed cotton for dolomite with nitrate of soda was probably due to the conversion of phosphorus into a less available form, or to a reduction in the water-soluble potash.

The response of cotton and vetch to sodium from nitrate of soda, and to dolomite and calcium limestone on Ruston fine sandy loam soil is shown by the unpublished data from Mississippi reported in Table 7. The limestone and dolomite were sufficient to make a neutral fertilizer. The vetch was planted over the band where the fertilizer was applied for the previous cotton crop without additional fertilizer treatment. Cotton gave no response to soda in this test, and probably none to limestone and dolomite; however, limestone and dolomite increased the yield of vetch about 50%, and the yield of vetch was doubled where nitrate of soda was used for cotton instead of sulphate

Table 7.—THE RESPONSE OF COTTON AND VETCH TO SOURCES OF NITROGEN.

Fertilizer treatment	Yield—lbs. per acre	
	Seed cotton	Vetch
800 lbs. 8-8-4 Sulphate of ammonia...................	1,103	507
800 lbs. 8-8-4 Sulphate of ammonia and limestone......	1,043	738
800 lbs. 8-8-4 Sulphate of ammonia and dolomite.......	1,166	817
800 lbs. 8-8-4 Nitrate of soda......................	1,061	1,088

of ammonia. The increase in yield of vetch where nitrate of soda was applied to cotton may be attributed to a need for soda or to the effect of soda on the availability of the applied phosphorus.

The application of dolomite with sulphate of ammonia to make a neutral fertilizer did not overcome its inferiority to nitrate of soda in 358 experiments in Alabama (25), Table 8. On the Hartselle and

Table 8.—THE RESPONSE OF COTTON TO SOURCES OF NITROGEN, DOLOMITE, AND SUPERPHOSPHATE

Source of nitrogen	Soil group and number of tests					
	Greenville 74	Decatur 77	Norfolk 98	Hartselle 61	Clarksville 48	Average 358
	Yield—pounds seed cotton per acre					
Nitrate of soda.....	1,007	1,044	1,021	1,207	985	1,050
Sulphate of ammonia and dolomite..	988	1,022	989	1,166	946	1,020
Sulphate of ammonia.............	977	990	940	1,100	856	974
	Increase in yield—pounds see cotton per acre					
For nitrate of soda over sulphate of ammonia and dolomite..........	19	22	32	41	39	30
For dolomite.......	11	32	49	66	90	46
For superphosphate.	218	193	262	287	299	246

The fertilizer treatment was 600 pounds of 6-10-4 fertilizer per acre.

Norfolk soils, nitrate of soda made 40 pounds more seed cotton than sulphate of ammonia and dolomite, which has a value of $2.00 per acre[1]. On the basis of these data a ton of 6-10-4 fertilizer containing nitrate of soda as the source of nitrogen applied to 3 1/3 acres produced $6.67 more cotton than a ton of neutral 6-10-4 fertilizer in which sulphate of ammonia and dolomite were used. On the average, nitrate of soda produced $5.00 worth of seed cotton per ton of 6-10-4 fertilizer more than did a neutral fertilizer containing sulphate of ammonia and dolomite (1940 prices).

The above data show that as the response to superphosphate by soil groups increased, the response to dolomite increased and the superiority of nitrate of soda over sulphate of ammonia and dolomite increased. The respective increases in yield by soil groups were: for

[1]Seed cotton was valued at 5 cents per pound.

FIG. 3.—Cotton fertilized with complete acid fertilizer plus limestone plus sulphur on left. No limestone or sulphur on right (24). (Courtesy Alabama Agricultural Experiment Station.)

dolomite, 11, 32, 49, 66, and 90; for superphosphate, 218, 193, 262, 287, and 299; and for nitrate of soda over sulphate of ammonia and dolomite, 19, 22, 32, 41, and 39 pounds of seed cotton per acre.

When the above data are calculated on the basis of the cost of fertilizers delivered to the farm, the following figures are obtained:

Cost of 2,000 pounds of sulphate of ammonia ...$36.00
Cost of 2,400 pounds of dolomite 6.00
                                                          _____
Total cost of sulphate of ammonia and dolomite. .$42.00
Cost of 2,500 pounds of nitrate of soda. $45.00

The cost of mixing the dolomite in the fertilizer and distributing 1,900 pounds of extra fertilizer is probably as much as the $3.00 difference in cost. On the basis of the average data, 2,500 pounds of nitrate of soda made 333 pounds of seed cotton valued at $16.65 more than 2,000 pounds of sulphate of ammonia and 2,400 pounds of dolomite. On the Hartselle soils (61 experiments) the difference was $27.35 (1940 prices).

Ammonium nitrate and dolomite in the form of calnitro were inferior to nitrate of soda for cotton production in 140 experiments (24) in Alabama:

Source of nitrogen	Yield-pounds of seed cotton per acre
Nitrate of soda	944
Calnitro	916

Nitrate of soda produced 28 pounds more seed cotton than did calnitro (dolomite and ammonium nitrate). In the 358 experiments reported

above, nitrate of soda made an average of 30 pounds per acre more seed cotton than did sulphate of ammonia and dolomite.

Calcium nitrate was as efficient for cotton production as was nitrate of soda in 82 experiments in Alabama (24):

Source of nitrogen	Yield-pounds of seed cotton per acre
Nitrate of soda	960
Calcium nitrate	958

With nitrate of soda and calcium nitrate there were sufficient soluble soda and calcium combined with the nitrogen to neutralize the acid formed. With these sources of nitrogen the calcium and sodium could diffuse out of the fertilizer zone with the nitrogen.

Where sulphate of ammonia and ammonium nitrate were used with dolomite, these nitrogenous fertilizers may have diffused out of the fertilizer zone, leaving the relatively insoluble dolomite in contact with the superphosphate in the fertilizer zone. These data suggest that the use of soluble sources of nitrogen which are non-acid-forming, is more desirable than the use of acid-forming sources of nitrogen and relatively insoluble dolomite in the fertilizer mixture. It should be pointed out that a 6-10-4 fertilizer, which contains more phosphorus than is normally recommended, was used. With less phosphorus the presence of dolomite and acid-forming sources of nitrogen in the fertilizer as compared to soluble sources of nitrogen containing calcium or soda, the difference might have been greater.

Nitrate of soda was superior to sulphate of ammonia plus lime to neutralize the acidity for cotton production on sandy soils of low fertility in southeastern Alabama (11) as shown by data in Table 9. The

Table 9.—Nitrate of Soda Versus Sulphate of Ammonia and Dolomite for Cotton Production on Sandy Soils of Low Fertility

Fertilizer applied at rate of 600 lbs. per acre	Number of tests	Sulphate of ammonia plus dolomite to neutralize	Nitrate of soda	Increase for nitrate of soda
		Yield—pounds of seed cotton per acre		
6-8-4	14	792	931	139
6-8-8	4	863	1,076	213
6-8-12	10	858	993	135
10-8-4	10	935	1,084	149
10-8-12	9	1,070	1,168	98
	Average of 47 tests			139

superiority of nitrate of soda to sulphate of ammonia and dolomite was apparently significant in all tests. There was no indication that the response of cotton to the soda in the nitrate of soda decreased as the amount of potash in the fertilizer increased.

Sulphate of ammonia and lime were nearly as efficient as nitrate of soda for cotton production on fertile soils in Alabama as shown by the following data (11):

Treatment	Average yield of seed cotton for 9 locations—lbs. per acre
Nitrate of soda................................	1,369
Sulphate of ammonia and lime to neutralize acidity....................................	1,353

In the case of the fertile soils, nitrate of soda was only slightly superior to sulphate of ammonia and lime. Since the data are for nine locations, the difference of 16 pounds of seed cotton per acre in favor of nitrate of soda may be significant.

Without evidence to the contrary, it might be as logical to attribute the superiority of nitrate of soda to its effect on the availability of the phosphorus, as it is to associate it with the requirement of plants for sodium or with potash deficiency.

The response of cotton to dolomite in acid-forming fertilizers is shown by data (Table 10) from 2,780 tests conducted by the Georgia Agricultural Experiment Station (1). The response to dolomite was small the first year of the tests except on a few soils; on the last year cotton gave a good response to dolomite on most soils. Dolomite overcame the harmful effect of the acid-forming sources of nitrogen.

The use of large quantities of dolomite or other liming material in the drill with complete fertilizers is questionable. The unpublished data reported in Table 11 were collected by the Mississippi Agricultural Experiment Station. The 600 pounds of dolomite per acre was applied in the drill with the high analysis fertilizers, when it should have been broadcast. On this year the cotton receiving the high analysis fertilizers showed symptoms of potash deficiency by early summer, which persisted until fall. The cotton receiving 14-28-14 had more pronounced potash deficiency symptoms than that on the other plots.

When the final yields were taken, the plots receiving 8-16-8, 10-20-10, and 14-28-14 produced less cotton in 1942 than on the 4-8-4 and 6-12-6 plots. Since, during the two following years, the high analysis fertilizers made as much or more seed cotton than the 4-8-4 and 6-12-6

Table 10.—YIELD OF SEED COTTON AS AFFECTED BY THE USE OF DOLOMITIC LIMESTONE IN MIXED FERTILIZERS.

Soils[1]	No. of tests	Yield		Increase for dolomite		
		Dolomite absent	Dolomite present	Average	First year	Last year
		Pounds of seed cotton per acre				
Coastal Plains						
Norfolk...............	722	860	913	55	15	92
Tifton.....,........	428	804	880	76	53	112
Ruston...............	18	699	724	25	−42	76
Orangeburg............	394	870	891	21	5	−18
Greenville.............	24	804	793	−11	..	..
Coastal Plain........	1,586	840	888	48	23	71
Piedmont						
Appling..............	264	668	765	97	56	158
Cecil.................	311	831	884	53	−10	92
Lloyd................	8	634	656	22	4	41
Davidson.............	228	788	820	32	35	38
Piedmont...........	811	763	826	63	31	111
Limestone Valleys						
Conasauga............	84	569	868	299	129	571
Clarkesville...........	60	874	922	48	47	26
Dewey...............	160	999	1,005	6	23	65
Decatur..............	64	1,551	1,544	−7	80	107
Huntington...........	15	741	969	228	157	282
Limestone Valley.....	383	1,075	1,140	67	77	206
Average................	2,780	852	905	53	34	106

[1]Source of nitrogen: sulphate of ammonia, or mixtures of sulphate of ammonia and other materials.

Table 11.—THE EFFECT OF HIGH AMOUNTS OF DOLOMITE IN THE DRILL WITH THE FERTILIZER ON THE YIELD OF COTTON IN 1944.

Fertilizer analysis[1]	Dolomite treatment		Yield—lbs. seed cotton per acre		
	Lbs. per acre	Years applied	1942	1943	1944
None.............	.....	.....	552	718	830
4-8-4..............	None	....	1,255	1,009	1,170
4-8-4..............	120	annually	1,244	1,038	1,144
6-12-6.............	96	annually	1,308	975	1,182
8-16-8.............	600	1942 only	1,159	1,072	1,168
10-20-10...........	600	1942 only	1,130	1,047	1,248
14-28-14...........	600	1942 only	851	974	1,222

[1]Applied at rates to supply 24 lbs. of nitrogen, 48 lbs. of phosphate, and 24 lbs. of potash per acre annually.

fertilizers, it is concluded that the 600 pounds of dolomite applied in contact with the high analysis fertilizers reduced the solubility of the potash, as indicated by potash deficiency symptoms and lower yields.

Under the program of the Agricultural Adjustment Administration considerable lime is being used. It is often broadcast over unplowed land, after which fertilizers are drilled in the water furrow and the land is bedded. Under these conditions very high quantities of lime
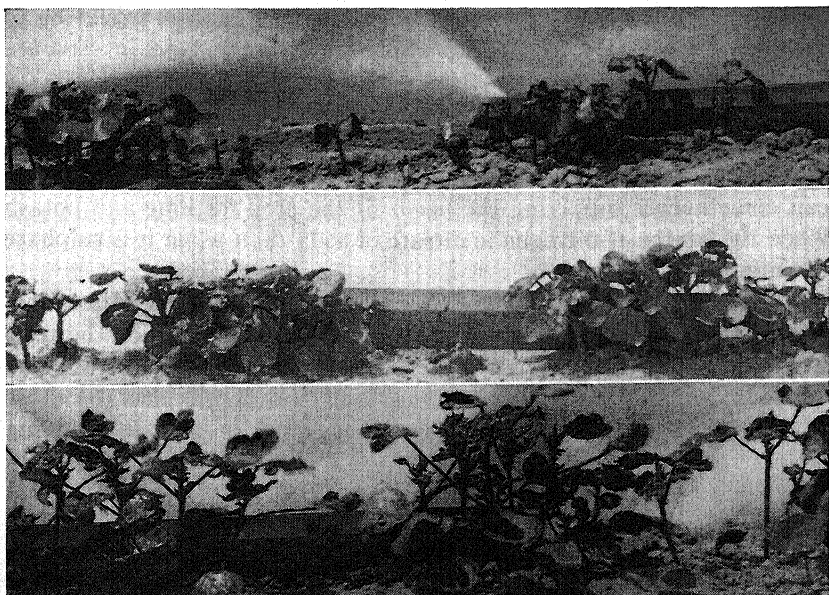

Fig. 4.—Cotton seedlings require sulphur. All of the cotton received a purified fertilizer containing nitrogen, phosphorus, and potash. In addition, limestone was applied in center, and calcium sulphate below (24). (Courtesy Alabama Agricultural Experiment Station.)

may come in direct contact with the fertilizer. If the success of the crop is dependent upon the potash applied, the excessive amount of lime in contact with the fertilizer may reduce the yield markedly through a reduction in the water-soluble potash.

Plant nutrient deficiencies often show up where excessive amounts of lime remain from piles from which lime has been distributed. High lime spots in the Middle West often respond to potash even though the soils have sufficient available potash, according to chemical methods.

Recent data collected by the Mississippi Agricultural Experiment Station introduce a question concerning the use of dolomite to neutralize acid-forming fertilizers (See page 287). Where part of the dolo-

mite was mixed with superphosphate several weeks in advance of application to the soil, 110 pounds less seed cotton was produced than where all of it was mixed in the complete fertilizer a few days in advance of planting. In most experimental work the dolomite has probably been mixed with the complete fertilizer only a few days in advance of application. Information is not available on the season dolomite is mixed with the other materials in complete fertilizers. However, the data suggest that there may be some question about the use of dolomite in mixed fertilizers. The alternative would be to use acid-forming fertilizers, and apply lime to the land in separate operations.

Chemical analyses (3) show that crops receiving sulphate of ammonia are higher in lime and potash than those that receive nitrate of soda (New York), which suggests that soils low in lime and potash can come nearer supplying the needs of the crop for lime and potash when the source of nitrogen is nitrate of soda than when it is sulphate of ammonia.

The response of cotton to sources of nitrogen in the Mississippi Delta (15) is shown by data in Table 12. The soils on which the tests were conducted fall into two separate classifications naturally, i.e., (a) those which had sufficient potash and phosphorus and (b) those which gave a small response to phosphorus and potash. In studying

'G. 5.—Nitrogen made the difference in growth of cotton in Alabama (24). (Courtesy Alabama Agricultural Experiment Station.)

the data presented it should be borne in mind that most of the tests have been conducted for too short a period for the fertilizers to have exerted a marked influence on the soil, and that the data are essentially a measure of crop response to sources of nitrogen.

On the soils which had sufficient phosphorus and potash there was little difference in the response of cotton to nitrate of soda, sulphate of ammonia, calcium nitrate, and calnitro; and cyanamid produced slightly less cotton than did the latter sources of nitrogen. Uramon (urea) showed up well in two tests and poor in the other test.

On the soils which were low in phosphorus and potash for cotton production, nitrate of soda was decidedly superior to all other sources of nitrogen. There was little difference between the yield produced by sulphate of ammonia, calnitro, calcium nitrate, and uramon. Cyanamid was slightly inferior to the latter sources of nitrogen. Three hundred and twenty pounds of nitrogen in nitrate of soda produced 1,080

Table 12.—THE RESPONSE OF COTTON TO SOURCES OF NITROGEN IN THE MISSISSIPPI DELTA.

Number and Location	Years in test	Source of Nitrogen					
		Nitrate of soda	Sulphate of ammonia	Cyanamid	Calcium nitrate	Calnitro	Uramon
		Increase in yield from 320 pounds of nitrogen on 10⅔ acres					
		Soils giving little or no response to superphosphate and potash					
1. Old sources...	21	5,444	4,402	4,125	.....	4,979[1]	.....
2. New sources..	14	4,275	4,564	.....	4,012	.....	.....
3. Heathman...	3	5,653	4,736	4,736	.....	5,024	5,280[2]
4. Morehead....	9	2,333	2,676	2,386	3,105	.....	.....
5. Hemphill....	7	3,099	2,293	2,272	3,061	2,795	3,211
6. Smith.......	3	5,137	4,709	5,179	4,681	4,470	3,156
Average 1-6........		4,324	3,897	.....	.....	.....	.....
Average 1, 3-6.......		4,333	3,763	3,740	.....	.....	.....
Average 2, 4-6.......		3,711	3,560	.....	3,715	.....	.....
Average 1, 3, 5-6......		4,833	4,035	4,078	.....	4,317	.....
Average 3, 5-6........		4,630	3,913	4,062	.....	4,096	3,882
		Soils responding to superphosphate and potash					
Atkinson.............		4,094	3,622	2,919	3,003	2,706	2,828
Schaeffer.............		6,293	4,469	4,149	6,016	5,579	4,565
Ladd................		5,713	4,414	4,023	3,623	4,576	4,681
Average............		5,367	4,168	3,697	4,214	4,287	4,025

[1]Ammonium nitrate limestone.
[2]Mixture of uramon and dolomite.

pounds of seed cotton more than any other source of nitrogen, the value of which is more than sufficient to pay for the fertilizer at the 1940 price of cotton. One ton of nitrate of soda contains 320 pounds of nitrogen.

Nitrate of soda produced 1,153 pounds more seed cotton than calcium nitrate per 320 pounds of nitrogen. Since the nitrogen in both sources was nitrate nitrogen, with the exception of a very small amount of ammonia nitrogen in the calcium nitrate, the difference is attributed to an advantage for sodium over calcium on soils low in available phosphorus and potash.

Table 13.—The Response of Cotton to the Soda in Nitrate of Soda.

Source of Nitrogen[1]	Pounds potash per acre	10-Year average	
		Yield	Increase for nitrate of soda over calcium nitrate
		Pounds per acre	
Calcium nitrate..............	0	306	...
Nitrate of soda..............	0	521	215
Calcium nitrate..............	15	742	...
Nitrate of soda..............	15	943	201
Calcium nitrate..............	45	1,093	...
Nitrate of soda..............	45	1,280	187
Calcium nitrate..............	60	1,201	...
Nitrate of soda..............	60	1,383	182

[1]All plots received 45 pounds nitrogen, 60 pounds phosphate and potash a indicated.

The superiority of nitrate of soda over calcium nitrate for cotton production on certain soils (7) is also illustrated by data from South Carolina (Table 13). With 0, 15, 45, and 60 pounds of potash per acre, nitrate of soda made 215, 201, 187, and 182 pounds of seed cotton per acre, respectively, more than calcium nitrate. With nitrate of soda 45 pounds of potash was superior to 60 pounds of potash with calcium nitrate. Since 60 pounds of potash would usually be considered sufficient potash for cotton production, the data indicate that the element sodium increased the yield of cotton. The nitrate of soda contained soda equal to 171 pounds of potash, and its beneficial effect could be indirect. Data are presented on pages 90 and 94 which show that the available potash in the soil was maintained at a higher level where

FIG. 6.—Effect of soda in nitrate of soda on the growth of cotton without potash. Left superphosphate and nitrate of soda, right superphosphate and calcium nitrate (8). (Courtesy South Carolina Agricultural Experiment Station.)

nitrate of soda was applied than where calcium nitrate was applied.

The response of cotton to sodium (9) in table salt is illustrated by data in Table 14. Table salt alone increased the yield 86 pounds of seed cotton per acre. The combination of 10 pounds of soda ash and 30 pounds of potash produced as much cotton as more potash and less soda ash, and 102 pounds more seed cotton per acre than 30 pounds of potash from muriate of potash.

Table 14.—COMPARATIVE YIELDS OF SEED COTTON FROM THE USE OF VARIOUS COMBINATIONS OF TABLE SALT AND MURIATE OF POTASH (11 YEARS).

Soda ash[1]	Potash	Yield	Increase
		Pounds per acre	
None	None	415	. . .
40	. .	501	86
35	5	693	278
30	10	773	358
25	15	801	386
20	20	910	495
15	25	943	528
10	30	1,079	664
5	35	1,084	669
. .	40	1,050	635
Check	30	981	566

[1]From table salt.

The difference between crop response to nitrate of soda and sulphate of ammonia is brought out by the data (20) in Table 15 for a 50-year period. Potash increased the yield of mangolds and sugar beets only 0.49 tons per acre where nitrate of soda was used as the source of nitrogen, and 6.80 tons where sulphate of ammonia was used. The difference in yield in favor of nitrate of soda over sulphate of ammonia was 7.93 tons without potash and 1.62 tons per acre with potash. The use of potash fertilizer, which probably contained some soda as table salt, reduced but did not eliminate the difference between these two sources of nitrogen.

Table 15.—THE RESPONSE OF SUGAR BEETS AND MANGOLDS TO SOURCES OF NITROGEN.

Mineral fertilizer	Average yield of 50 crops of mangolds and sugar beets	
	Nitrate of soda	Sulphate of ammonia
	Tons per acre	
Complete minerals..................	17.35	14.37
Superphosphate and potash..........	15.12	13.50
Superphosphate only...............	14.63	6.70
Increase for potash.................	0.49	6.80

The superiority of nitrate of soda over sulphate of ammonia for the production of sugar beets and mangolds may be due to the requirement of these crops for soda, or to some indirect effect.

The effect of fifteen years fertilization using nitrate of soda as the source of nitrogen on the phosphorus and potash requirement of cotton is shown by data from Mississippi[1] (Table 16). The potash requirement of cotton was reduced from 48 to 36 pounds per acre, and the phosphate requirement was reduced from 48 to not more than 24 pounds per acre during the 15-year period. The reduction in the potash requirement is attributed to the sodium in the nitrate of soda reducing the loss of potash by leaching. This soil was neutral in reaction, and the reduction in the superphosphate requirement is attributed to the accumulation of available phosphorus as a result of using superphosphate and nitrate of soda.

The effect of sulphate of ammonia on the phosphorus and potash requirement of cotton is opposite to the effect of nitrate of soda

[1] Published at various times by the Holly Springs Branch Station.

(Table 17). The average increase in yield due to superphosphate where sulphate of ammonia was used as the source of nitrogen was 91 pounds of seed cotton the first three years, and 123 pounds the second three years. The greater response to superphosphate during the last three years is attributed to the effects of sulphate of ammonia on the leaching of lime and on the available phosphorus in the soil. The average increase in yield due to potash was 8 pounds of seed cotton per acre for the first three years and 93 pounds for the second three years. Sulphate of ammonia evidently speeded up leaching and

Table 16.—THE EFFECT OF 15 YEARS OF FERTILIZATION WITH NITRATE OF SODA ON THE PHOSPHORUS AND POTASH REQUIREMENT OF COTTON.

Treatment	Increase in yield by 5 year periods	
	First[1]	Last
	Pounds per acre	
Varying potash		
600 lbs. 4-8-0	163	156
600 lbs. 4-8-2	399	511
600 lbs. 4-8-4	557	717
600 lbs. 4-8-6	694	836
600 lbs. 4-8-8	804	798
Varying phosphorus		
600 lbs. 4-4-4	398	649
600 lbs. 4-6-4	496	674
600 lbs. 4-8-4	557	717
Varying nitrogen		
600 lbs. 4-8-4	557	717
600 lbs. 6-8-4	568	710
600 lbs. 8-8-4	532	660
No fertilizer	860	905

[1]Omitting the first year.

brought about a definite need for potash on soils which needed little potash when the tests were started.

The response of tobacco to sources of nitrogen is shown by the data (2) in Table 18. The different sources of nitrogen produced the same yield of tobacco. The quality of the tobacco as indicated by grade and crop index was superior where nitrate of soda was used as the source of nitrogen. The burning quality of the tobacco receiving nitrate of soda was superior, and that receiving sulphate of ammonia was distinctly inferior. The quality of the tobacco where the other sources of nitrogen were used was intermediate.

Table 17.—The Effect of Six Years Fertilization with Sulphate of Ammonia on the Superphosphate and Potash Requirement of Cotton.*

Soil Type	1934	1935	1936	1937	1938	1939	Average First 3 years	Average Second 3 years
Increase for superphosphate—lbs. seed cotton per acre								
Cahaba fine sandy loam.......	106	—46	172	93	302	29	77	141
Kalmia fine sandy loam........	132	89	375	286	381	74	199	247
Atwood fine sandy loam.......	280	185	480	467	260	246	315	324
Ruston fine sandy loam No. 1..	31	43	121	134	205	22	65	120
Grenada silt loam.............	100	42	81	—16	127	—8	74	34
Ruston sandy loam No. 2......	73	12	—43	98	148	41	14	96
Oliver silt loam...............	120	14	—28	203	—14	9	35	66
Savannah very fine sandy loam.	251	113	23	133	34	31	129	66
Pheba very fine sandy loam....	—82	—51	—20	—4	165	69	—51	77
Oktibbeha clay...............	73	—56	29	26	87	61	53	58
Average 10 soils.............	108	46	119	142	170	57	91	123
Increase for potash—lbs. seed cotton per acre								
Cahaba fine sandy loam.......	58	38	68	277	206	105	55	196
Kalmia fine sandy loam........	40	61	139	434	41	100	80	192
Atwood fine sandy loam.......	12	—3	80	123	156	272	30	184
Ruston fine sandy loam No. 1..	7	23	117	122	77	250	49	150
Grenada silt loam.............	31	46	181	60	151	64	86	92
Ruston sandy loam No. 2......	106	—45	—27	—122	238	8	11	41
Oliver silt loam...............	31	—7	—114	72	—34	58	—30	32
Savannah very fine sandy loam.	—5	34	—41	25	—24	77	—4	26
Pheba very fine sandy loam....	—90	—30	—160	—32	—83	141	—93	9
Oktibbeha clay...............	—91	—89	—147	—30	—1	55	—109	8
Average 10 soils.............	10	2	10	93	73	113	8	93

*Unpublished data—J. L. Anthony, Mississippi Agricultural Experiment Station. The fertilizer treatment was 16 pounds of nitrogen (90% from sulphate of ammonia and 10% from cottonseed meal), 32 pounds of phosphate from superphosphate, and 16 pounds of potash from muriate of potash.

The response of tobacco to sources of nitrogen is shown by data from Maryland reported in Table 19. Cyanamid produced less tobacco at the 40-pound potash rate and the quality was lower than with other sources of nitrogen (14). Sulphate of ammonia and nitrate of soda produced high yields of tobacco of high quality. In other tests urea produced good yields of high quality tobacco. Ammonium chloride produced high yields of tobacco of very low value. The low value of

Table 18.—The Response of Tobacco to Sources of Nitrogen.

Source of nitrogen	Yield—pounds per acre 1932-'35	Grade index 1932-'35	Crop index 1932-'35	Burn in seconds 1932-'34 Darks	Burn in seconds Seconds
Nitrate of soda........	1,876	.410	770	12.3	30.5
Sulphate of ammonia...	1,852	.392	726	8.3	13.8
Cyanamid	1,863	.399	747	10.5	14.2
Urea.................	1,843	.400	738	9.5	20.0
Standard mixture[1]	1,890	.402	761	13.3	23.0

[1]Nitrogen: ½ cottonseed meal, ¼ calurea, ¼ potassium nitrate and nitrate of soda.

Table 19.—THE RESPONSE OF TOBACCO TO SOURCES OF NITROGEN

Source of nitrogen	Pounds of potash per acre					
	20		40		80	
	Yield lbs.	Value dollars	Yield lbs.	Value dollars	Yield lbs.	Value dollars
Cyanamid..............	846	173	852	164	.....	...
Ammonium nitrate.......	897	199	1,039	228	.....	...
Sulphate of ammonia.....	869	194	962	214	1,057	195
Ammonium chloride......	933	162	1,030	177	1,067	123
Nitrate of soda..........	873	180	972	201	1,064	181
No nitrogen............	632	93	.....	...	.....	...

the tobacco where ammonium chloride was applied is due to poor burning properties, which results from the absorption of high quantities of chlorine.

Data from South Carolina (19) on rate of application of nitrate of soda to cotton, corn, and oats show that up to 300 pounds of nitrate of soda per acre may be used with the normal prices of crops (Table 20).

Table 20.—THE RESPONSE OF COTTON, CORN, AND OATS TO RATES OF
NITRATE OF SODA.

	Yield per acre		
	Seed cotton	Corn	Oats
	Pounds	Bushels	Bushels
Number of experiments.............	15	18	18
No fertilizer[2]	519	15.9	23.1
No nitrate of soda...................	681	17.0	26.4
100 pounds of nitrate of soda........	903	21.6	39.9
200 pounds nitrate of soda..........	1,104	29.7	53.4
300 pounds nitrate of soda..........	1,180	33.5	62.4
400 pounds nitrate of soda..........	1,225	35.7	68.8[1]
400 pounds nitrate of soda	No phosphorus or potash		61.4

[1]Last two years only.
[2]Basic fertilizer treatment (except no fertilizer) for cotton, 400 pounds superphosphate and 50 pounds of muriate of potash. Corn and oats, 200 pounds superphosphate and 50 pounds muriate of potash.

In the Mississippi Delta (15), where the soils are productive, cotton, corn, and oats give profitable response to 30 pounds of nitrogen per acre, and as much as 45 pounds per acre may be used on cotton (Table 21). Some farmers are using as much as 80 pounds of nitrogen per acre on cotton in the Delta. The profitableness of fertilizers applied

Table 21.—THE RESPONSE OF COTTON, CORN AND OATS TO RATES OF NITRATE OF SODA IN THE MISSISSIPPI DELTA.

Rate of application of nitrogen as nitrate of soda	Increase in yield per acre		
	Seed cotton 19 years	Corn 19 years	Oats 13 years
	Pounds	*Bushels*	*Bushels*
7.5 pounds nitrogen.................	133	3	10
15 pounds nitrogen.................	231	7	22
22.5 pounds nitrogen................	357	11	29
30 pounds nitrogen.................	496	16	37
37.5 pounds nitrogen................	573	19	40
45 pounds nitrogen.................	600	19	43
No fertilizer yield.................	1,153	22	21

to cotton is dependent on the control of boll weevils. On the intensive cotton farms of the Delta where the best methods of applying boll weevil poison, including dusting with airplanes, are used, the boll weevil may be controlled quite well and maximum yields and response to fertilizers are obtained.

It is desirable to prepare heavy land for cotton or corn in the fall and winter and only freshen the beds up sufficiently in the spring to kill the weeds. Under these conditions, some farmers prefer to apply the fertilizers in the fall. In tests conducted in the Mississippi Delta, fall applications (15, 17) of nitrate of soda, sulphate of ammonia and cyanamid have been inferior to spring applications (Table 22). However, 30 pounds of nitrogen applied in the fall increased the yield of cotton 500 pounds, corn 15 bushels, and oats 30 bushels per acre. The high increase in yield of crops from fall applications of nitrogenous fertilizers on heavy soil suggests that little nitrogen was lost by leach-

Table 22.—THE EFFECT OF TIME OF APPLICATION ON THE RESPONSE OF COTTON TO SOURCES OF NITROGEN.

Source of nitrogen	Time of application	Increase in yield per acre		
		Cotton	Corn	Oats
		Pounds	*Bushels*	*Bushels*
Nitrate of soda............	November.....	506	18	33
Nitrate of soda............	March........	520	20	37
Sulphate of ammonia........	November.....	530	16	31
Sulphate of ammonia........	March........	588	19	35
Cyanamid................	November.....	531	14	28
Cyanamid................	March........	619	17	24

ing during the winter months. Since the above data are for only one test with each crop, and the good results obtained for fall-applied nitrogen to oats was not verified in any of the tests reported below, the general applicability of the results is questioned. Since applying nitrogen immediately before planting is more profitable than fall application, and side dressing is as profitable or more profitable than applications immediately before planting, it appears that side dressing cotton on land prepared in the fall should be more profitable than fall application; however, the distribution of labor is one of the factors which determine the time at which fertilizers are to be applied.

Fall application of ammonium nitrate to oats was inferior to spring application in ten tests conducted by the Mississippi Agricultural Experiment Station as shown by the following (unpublished) data:

Time of Application	Test number									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Increase in yield—bus. of oats per acre									
Spring ..	21	25	25	27	20	30	19	22	24	24
Fall.....	16	15	16	20	10	15	8	8	10	5

The rate of application was 32 pounds of nitrogen per acre. The oats were planted in October. The soils included all gradations in heaviness from light sandy loams to heavy clays. As compared to spring application fall-applied ammonium nitrate was not satisfactory on any soil. From the standpoint of grain production, fall application of the sources of nitrogen which are commonly used does not appear to be satisfactory.

The application of sulphate of ammonia in the spring produced larger yields of wheat (20) than fall applications on the Broadbalk, England plots (Table 23). The differences in favor of spring application of sulphate of ammonia over fall application were larger when high amounts of rainfall came during the winter. The loss of nitrogen by leaching during the winter months was significant when the rainfall was high.

The data (19) in Table 24 show that applying nitrate of soda as a side dressing for cotton was more profitable than applying it before planting. Applying 100 pounds of nitrate of soda before planting and 100 pounds as a side dressing three weeks after chopping made 94 pounds more seed cotton than putting all of it out before planting.

Table 23.—The Effect of Rainfall on the Response of Wheat to Time of Application of Nitrogen.

Range	October-March rainfall—inches Average	Difference in favor of spring application— bushels wheat per acre
Average all years, 1878-1928............	15.26	3.87
Years grouped according to rainfall		
Rainfall less than 12.4 inches...........	10.30	1.96
Rainfall between 12.4 in. and 14.1 in....	13.37	1.30
Rainfall between 14.1 in. and 16.1 in....	15.27	5.25
Rainfall between 16.1 in. and 18.0 in....	16.86	5.41
Rainfall greater than 18 in.	20.49	5.43

The value of 94 pounds of seed cotton is more than sufficient to pay for the nitrogen fertilizer.

Data presented in Chapter 16 on 9 tests show that applying two-thirds of the nitrogen before planting and two-third as a side dressing

Table 24.—The Effect of Time of Application of Nitrogen on the Yield of Cotton, Corn, and Oats (16 Tests).

Treatment	Yield per acre
Cotton—	pounds
No fertilizer..................................	601
No nitrate of soda.............................	740
200 lb. at planting............................	1,006
50 lb. at planting, 150 lb. at chopping........	1,033
200 lb. at chopping............................	1,042
100 lb. at planting, 100 lb. 3 weeks after chopping	1,100
100 lb. at planting, 100 lb. 6 weeks after chopping.............	992
100 lb. at chopping, 100 lb. 6 weeks after chopping.............	1,027
Corn—	bushels
No fertilizer..................................	16.2
No nitrate of soda.............................	18.2
200 lb. at planting............................	27.8
200 lb. when knee-high.........................	32.9
200 lb. when bunching to tassel................	29.1
50 lb. at planting, 150 lb. when knee-high.....	31.6
100 lb. when knee-high, 100 lb. when bunching to tassel........	30.8
Oats—	bushels[1]
No fertilizer..................................	21.1
No nitrate of soda.............................	23.3
200 lb. February 1.............................	48.3
200 lb. February 15............................	50.8
200 lb. March 1...............................	52.8
200 lb. March 15..............................	50.7

[1]Only 15 tests.

increased the yield 132 pounds of seed cotton per acre over applying all of the nitrogen before planting.

The data show that nitrate of soda should be applied to corn after it has been worked out. There was little difference in the yield of oats where 200 pounds per acre of nitrate of soda was applied February 1 and 15 and March 1 and 15.

All of the widely used sources of nitrogen were more efficient for cotton production when part of the nitrogen was used as a side dressing in one experiment in South Carolina (23). The data reported in Table 25 show that side dressing with part of the nitrogen increased the yield

Table 25.—THE EFFECT OF THE SOURCE AND TIME OF APPLICATION OF NITROGEN ON THE YIELD OF COTTON.

Time of application	Proportion of nitrogen				Average all times
Before planting.........	All	⅔	⅓	⅓	
After chopping.........	..	⅓	⅔	⅓	
Two weeks later........	..	..	..	⅓	
Source	*Yield—pounds of seed cotton per acre*				
Calnitro...............	1,937	2,089	2,034	1,927	1,997
Urea..................	1,840	2,036	2,073	1,957	1,977
Sulfate of ammonia.....	1,917	1,935	2,061	1,935	1,962
Nitrate of soda.........	1,735	1,939	1,975	1,862	1,878
Average all sources.....	1,857	2,000	2,036	1,920	......

of cotton with all sources of nitrogen used. Nitrate of soda was inferior to other sources of nitrogen in this test.

Side dressing cotton with part of the nitrogen is not always more profitable (21) than applying it all before planting (Table 26). The fertilizer used was a 5-9-3. The phosphorus and potash were applied before planting the cotton. The data show that applying all of the nitrogen before planting was better than applying part of it

Table 26.—TIME OF APPLICATION OF NITROGEN TO COTTON.

Time of application of nitrogen	Three-year average yield, pounds per acre		
	Nitrate of soda	Sulphate of ammonia	Urea
All under.............................	1,010	831	839
Half under—half at chopping............	766	655	713
One-third—under one-third at chopping—one-third 3 weeks later................	864	758	822

as side dressing. The above results may be due to surface application
on dry years. Entirely different results might have been obtained with
the application of the nitrogen used as a side dressing at a depth of
four inches. Most of the data available show that side dressing cotton
with part of the nitrogen is more profitable than applying all of it
before planting. On heavy soils, where leaching is a minimum, all of
the nitrogen may be applied before planting cotton.

Applying part or all of the nitrogen as a side dressing has certain
advantages over application before planting other than its effect on
yield. Owing to seasonal variations, not all crops which are planted
are cultivated to maturity, and occasionally the season may be such
that the crops are improperly worked. Where application of fertilizer
is made after the crop is up and worked out, judgment may be passed
on the condition of the crop with respect to the probability that a
profitable response to fertilizers may be obtained. Nitrogen stimulates
the growth of grasses, and heavy nitrogen fertilization before crops
are planted may increase the labor of keeping young crops clean.
Competition from the growing crops when the side dressing is applied
at a later stage of growth may help to control grass and enable the
cultivated plants to recover a larger percentage of the nitrogen applied.

High yields of corn were produced in North Carolina (18) with the
use of high rates of nitrogen where adequate stands of corn were left
and adequate phosphorus and potash were used (Table 27). The data

Table 27.—THE RESPONSE OF CORN TO HIGH RATES OF NITROGEN.

Pounds of nitrogen per acre	Yield—bus. of corn per acre, 11 tests
None	21
20	32
40	48
60	59
80	63
120	72

show an increase in yield of up to 51 bushels of corn per acre. The
high plant populations no doubt reduced the yield where little or no
nitrogen was applied. However, the data show that high yields of corn
may be produced with high fertilization when the value of corn justi-
fies the expenditure for the fertilizer.

When concentrated fertilizers are used, it is necessary to get part
or all of the nitrogen from ammonium phosphate, ammonium nitrate,

and urea. The data (22) reported in Table 28 show that sulphate of ammonia and urea were inferior to nitrate of soda, and ammonium phosphate was inferior to ammonium sulphate or urea and super-phosphate from the beginning of the test. Where single sources of nitrogen were used, nitrate of soda usually produced at least enough more seed cotton than sulphate of ammonia or urea to pay for the nitrogen. The mixtures in which sulphate of ammonia and urea were

Table 28.—YIELD OF COTTON FROM ORDINARY-ANALYSIS FERTILIZER AND CONCENTRATED FERTILIZER ON RUSTON SANDY LOAM—FAYETTEVILLE, N. C.

Fertilizer analysis N-P₂O₅-K₂O	Lbs. per acre	Source of fertilizer materials	Pounds per acre			Average
			Yield			
			1931	1932	1933	
5-8-8	800	Superphosphate, nitrate of soda, and potassium sulphate	2,100	1,437	2,150	1,896
5-8-8	800	Superphosphate, nitrate of soda, cottonseed meal, and potassium sulphate[1]........	2,025	1,538	2,125	1,896
10-16-16	400	Ammonium phosphate, nitrate of soda, and potassium sulphate.................	1,836	1,324	1,603	1,588
5-8-8	800	Superphosphate, sulphate of ammonia and potassium sulphate.................	1,975	1,387	1,788	1,717
5-8-8	800	Superphosphate, sulphate of ammonia, cottonseed meal, and potassium sulphate[1]....	2,075	1,537	1,862	1,825
10-16-16	400	Ammonium phosphate, sulphate of ammonia, and potassium sulphate............	1,675	1,292	1,557	1,508
5-8-8	800	Superphosphate, urea, and potassium sulphate........	1,975	1,437	1,762	1,725
5-8-8	800	Superphosphate, urea, cottonseed meal, and potassium sulphate[1].................	2,135	1,335	2,012	1,827
10-16-16	400	Ammonium phosphate, urea, and potassium sulphate.....	1,812	1,268	1,200	1,427
No fertilizer			1,025	762	870	886

[1] 35% of the nitrogen derived from cottonseed meal.

used with cottonseed meal were inferior to nitrate of soda. Ammonium phosphate was a poor substitute for superphosphate. Even though the high analysis fertilizer materials did not make a good showing in this test, other data are available which show that they may be used in formulating excellent fertilizers where consideration is given to sulphur and lime.

Sulphate of ammonia has been superior (21) to ammonium chloride as a source of nitrogen for cotton production:

Source of nitrogen	Yield of seed cotton—pounds per acre			
	Test 1	Test 2	Test 3	Test 4
Sulphate of ammonia.........	1,008	1,570	993	1,269
Ammonium chloride..........	924	1,420	905	1,180

Ammonium chloride is not offered for sale at the present time.

Sulphate of ammonia was inferior to nitrate of soda for top dressing oats on soils which are very high in lime (12), as occur in the black belt of Mississippi and Alabama:

Source of nitrogen	Soil type	
	Sumpter clay	Bell clay
	Increase—bus. oats per acre	
Nitrate of soda...........	12.5	19.5
Sulphate of ammonia......	11.3	10.0

The inferiority of sulphate of ammonia to nitrate of soda for the production of oats on soils which have excess lime is attributed to the loss of nitrogen into the air as ammonia gas where sulphate of ammonia is used. It is well known that ammonia is lost into the air when lime and sulphate of ammonia are mixed. The soils above contain very high amounts of lime, and it appears reasonable to attribute much of the inferiority of sulphate of ammonia in this case to the loss of nitrogen into the air.

Oats usually give better response to nitrate of soda than to other sources of nitrogen (12) on upland soils (Table 29).

Nitrogen applied in the fall prevented heaving of oats in 3 tests conducted in Mississippi in 1945-1946 (Figure 7). The fall-applied nitrogen stimulated the growth of oats and the development of a root system which was large enough to prevent the oats from heaving out of the ground. Without nitrogen about 80% of the oats were heaved out of the ground in one test.

The application of nitrogen to small grains in the fall to enable

Table 29.—THE RESPONSE OF OATS TO SOURCES OF NITROGEN.

Source of nitrogen	Pounds of nitrogen per acre	
	16 (13 Tests)	24 (13 Tests)
	Increase in yield—bushels per acre	
Nitrate of Soda.....................	17.8	25.2
Cyanamid.........................	10.5	16.7
Sulphate of ammonia................	14.3	22.6

them to withstand freezes may be of importance where they are planted late, or on soils which are low in nitrogen.

On fertile soils in the Mississippi Delta nitrate of soda was superior to other sources of nitrogen for oat production (12) over a period of

FIG. 7.—Nitrogen applied in the fall prevented heaving of oats. (Courtesy Mississippi Agricultural Experiment Station.)

13 years (Table 30). Ammonium nitrate was almost as efficient as nitrate of soda for the production of oats. Cyanamid and cottonseed meal were poor sources of nitrogen for oats.

Table 30.—THE RESPONSE OF OATS TO SOURCES OF NITROGEN IN THE MISSISSIPPI DELTA

Source of nitrogen[1]	Increase in yield of oats— bushels per acre (1928-1940)
Nitrate of soda......................	38.8
Ammonium nitrate.................	36.7
Sulphate of ammonia...............	31.0
Cyanamid.........................	24.2
Cottonseed meal....................	14.1
One-half cottonseed meal and one-half nitrate of soda............	24.9

[1] 30 pounds of nitrogen per acre.

Organic sources of nitrogen are often as efficient as inorganic sources when used as only part of the nitrogen, as is shown by the data (21) in Table 31. The unusually good results obtained for organic sources of nitrogen may be due to the high rate of nitrogen applied. Since no data are reported for plots without nitrogen, the total increase in yield due to nitrogen is problematical. Organic sources of nitrogen cost about three times as much per pound of nitrogen as other sources; they are entirely too expensive to use for fertilizer. Normally, animal tankage and oil seed meal are used largely for animal feed.

Table 31.—THE EFFECT OF VARIOUS SOURCES OF NITROGEN IN MIXED FERTILIZER ON YIELD OF COTTON.

Source of nitrogen in 900 pounds 6-8-4 fertilizer per acre	Soil type	
	Norfolk very fine sandy loam (6 years)	*Marlboro sandy loam (3 years)*
	Yield—pounds of seed cotton per acre	
Nitrate of soda.....................	1,203	1,400
Sulphate of ammonia...............	1,059	1,270
33% nitrate of soda, and 67% sulphate of ammonia................	1,107	1,290
67% nitrate of soda, and 33% sulphate of ammonia................	1,273	1,380
25% nitrate of soda, 25% sulphate of ammonia, and 50% dried blood....	1,250	1,400
25% nitrate of soda, 25% sulphate of ammonia, and 50% cottonseed meal.	1,255	1,400

For potatoes in Maine the experimental results (6) show that sulphate of ammonia and nitrate of soda (Table 32) produced equal yields. Urea, leunasalpeter, ammonium chloride, and fish meal were excellent sources of nitrogen for potatoes. Harmful results were reported from a deficiency of lime with long continued use of acid-forming fertilizers on potatoes, which could be corrected by the use of 500 pounds of lime per acre per year.

Difference in the leaching of nitrate and ammonia nitrogen are shown by the data (24) presented in Table 33. The data show that nitrate nitrogen is more easily leached from the soil than ammonia nitrogen. Ammonia nitrogen combines with clay to form ammonia clay. Since clay does not leach out of the soil, it prevents nitrogen

Table 32.—The Response of Potatoes to Sources of Nitrogen.

Source of nitrogen[1]	Number of years per test				
	16	6	3	3	2
	Yield—bus. of potatoes per acre				
Nitrate of soda.............	307	279	348	310	266
Sulphate of ammonia.......	315	290	355	313	272
Ammonium chloride........	...	311	...	...	277
Ammonium nitrate.........	...	311	...	...	...
Ammonium phosphate......	...	311	...	...	...
Calcium nitrate............	...	...	344	...	...
Cyanamid.................	...	...	335	...	...
Leunasalpeter.............	...	...	356	...	...
Urea.....................	...	313	351	348	...
Fish meal.................	...	...	359	...	..
No nitrogen..............	...	190	270	220	...

[1] 1,500 or 1,800 pounds of 3.3-8-8 or 4.1-8-7 fertilizer per acre.

combined with it from leaching out of the soil. Nitrate nitrogen does not combine with the clay; it stays in the soil water. When water leaches through the fertilizer zone, the nitrate nitrogen may be largely leached out, while most of the ammonia nitrogen on the clay stays in the soil. Both nitrate and ammonia nitrogen are much more easily leached out of sandy than clay soils. The above data illustrate differences between the properties of nitrate and ammonia nitrogen; usually these data would not have any practical application in the field, as is shown below.

Table 33.—Leaching of Nitrate and Ammonia Nitrogen

Water added, inches	Soil type			
	Norfolk sand loam		Cecil clay	
	Nitrate of soda	Sulphate of ammonia	Nitrate of soda	Sulphate of ammonia
	Percentage of nitrogen leached[1]			
1	0	0	0	0
2	39	23	7	0
3	65	34	29	1
4	69	37	48	2
5	79	37	61	2
6	76	41	73	6

[1] 75 pounds of nitrogen was applied per acre.

Under field conditions, even though nitrate nitrogen is more subject to leaching than ammonia nitrogen, nitrate of soda made (Alabama)

more seed cotton (24, 25) than sulphate of ammonia on Norfolk soils, which leach badly, when all of the nitrogen was applied before planting cotton:

Source of nitrogen	Increase in yield—lbs. seed cotton per acre	
	57 tests	98 tests
Nitrate of soda.....................	320	343
Sulphate of ammonia................	262	...
Sulphate of ammonia and dolomite....	...	311

When heavy rains fall immediately after the application of fertilizers on sandy soils, more nitrogen may be lost where nitrate of soda is applied than where sulphate of ammonia is applied. Since nitrate of soda on the average has been superior to other sources of nitrogen which leach less readily on the soils most subject to leaching, a change from nitrate nitrogen to forms which leach less readily would not be justified on the basis of leaching. Regardless of the source, the leaching of nitrogen during seasons of heavy rainfall may be sufficient reason for applying only part of the nitrogen under crops and part of it as a side dressing every year, particularly for corn and cotton.

When nitrogen was derived from sulphate of ammonia, a so-called non-leaching form of nitrogen, side dressing with part of the nitrogen was as profitable as where nitrate of soda was used (see page 25). When two-thirds of the nitrogen was applied under cotton and one-third as a side dressing, 132 pounds more seed cotton was made than when all of the nitrogen was applied before planting. These data are opposite to the suggestion that the application of so-called non-leaching forms of nitrogen, like sulphate of ammonia, before planting are as satisfactory as nitrate of soda used as a side dressing for cotton production.

There is only a short period of time when differences exist in leaching of nitrogen applied in the ammonia and nitrate forms, for ammonia nitrogen is usually converted into nitrate nitrogen in 4 to 6 weeks. Leaching could possibly produce significant differences in the loss of these two forms of nitrogen immediately after application. After one month there should not be a measurable difference in the loss by leaching of nitrogen applied in these two forms. Under field conditions, differences in yield due to differences in the leaching of nitrate and ammonia nitrogen are rarely realized.

On the Broadbalk wheat field (20) in England the difference in

Table 34.—THE EFFECT OF RAINFALL ON THE RESPONSE OF WHEAT TO NITRATE OF SODA AND SULPHATE OF AMMONIA.

Period 1854-84 Rainfall	Increase for nitrate of soda over sulphate of ammonia	Period 1885-1928 Rainfall	Increase for nitrate of soda over sulphate of ammonia
Inches	Bushels wheat per acre	Inches	Bushels wheat per acre
Below 25.5	0.8	Below 25	4.9
25.5—31	6.3	25-29.35	5.6
Above 31	6.3	29.35—31.5	5.7
		Above 31.5	5.1
Average 28.7	4.5	Average 28.9	5.3

favor of nitrate of soda over sulphate of ammonia was greater during wet years than during dry years (Table 34). "The effect, however, is complicated by the fact that the dry years happened to occur at the beginning of the period, and the wet ones at the end; and soil exhaustion has proceeded differently on the two plots."

The comparative effect of level and ridge cultivation on corn, cotton and sudan grass production, and on the accumulation of nitrates in the soil was studied by the Louisiana Agricultural Experiment Station (5). In the case of cotton, planting and cultivation on high ridges on fertile soil gave greater vegetative growth than planting and cultivating flat; however, greater yields were not always obtained with ridge cultivation, due to boll weevils and diseases. The data for corn and sudan grass are reported in Table 35.

Table 35.—THE EFFECT OF RIDGE, LEVEL, AND FURROW CULTIVATION ON THE YIELD OF CROPS AND ON THE ACCUMULATION OF NITRATE NITROGEN IN THE SOIL.

Years of test	Soil	Type of culture		
		Ridge	Level	Furrow
		Yield of corn—bushels per acre		
5	Bench..........	43.8	39.6	....
1	Bench..........	33.7	30.9	....
2	Bench..........	34.6	30.6	30.5
3	Alluvial........	37.2	32.4	35.4
		Yield of sudan grass—pounds per acre		
1	....	8,055	7,481	6,617
		Pounds nitrate nitrogen per acre in fallow land June 8		
1	....	92	65	....

The corn on the bench land was fertilized with 600 pounds of 6-10-5 fertilizer per acre. Corn and soybeans were grown together on the alluvial land. On the average, corn on high ridges produced about 4 bushels more per acre than corn cultivated level or in furrows. Sudan grass grown on ridges produced significantly more than that cultivated level or in furrows. The crops on the ridges grew off more rapidly and had a darker green color than those cultivated level or in furrows.

The reason for the superiority of ridge over level culture is suggested by the data on nitrate nitrogen. The land which was maintained level lost 27 pounds of nitrate nitrogen (equal to 169 pounds of nitrate of soda) per acre by leaching more than the ridged land. Where land is maintained in ridges, the excess water quickly runs off of the ridge into the water furrow, where it moves down and leaches into the subsoil without going through much of the top soil containing the nitrate nitrogen, which is leachable. Where the land is maintained level, leaching takes place directly through the soil, and considerable quantities of nitrogen are apparently lost by leaching.

The above differences in yield took place on silt loam and clay soils. These soils are quite heavy, and leaching is much less than on the sandy loam soils which predominate throughout the eastern half of the country.

The influence of height of ridge on the yield of sweet potatoes is shown by data (10) collected in South Carolina:

Height of ridge	Bushel sweet potatoes per acre	
Inches	Yield	Increase
0 to 2	238	. . .
6 to 8	275	37
12 to 14	288	50

Where the sweet potatoes were grown on ridges 6 to 8, and 12 to 14 inches high, the yields were 37, and 50 bushels per acre, respectively, higher than where they were grown without ridging. As was the case on fallow soil (above), the ridges probably conserved more nitrate nitrogen against leaching.

In the Southeast, cotton, corn, tobacco, and other crops are commonly planted on ridges. For the first cultivation, it is not uncommon for these crops to be barred off with a turning plow, leaving them on a ridge about 4 inches wide with deep furrows on each side. The next plowing may be with a small sweep in the barred off furrow, after which the middles are plowed out at some future date. Small sweeps

which leave furrows next to the young crops may be used for a second and third cultivation. These furrows accumulate rain water, which leaches down through the soil. Since most of the fertilizer is applied under the ridge, the leaching water may remove large quantities of nitrogen and potash. The extent to which these plant nutrients are lost depends on the soil. The losses are much greater on sandy soils. It appears that cultivation should be carried out in such a manner as to maintain high ridges.

The use of ammonia and nitrate nitrogen by young cotton seedlings was studied by the Alabama Agricultural Experiment Station (24). The data show that:

1. Ammonia nitrogen was used in larger amounts than nitrate nitrogen until the young plants were three to five weeks old.
2. Both ammonia and nitrate nitrogen were used in large amounts when the plants were four to eight weeks old.
3. Both fruiting and growth were better when both forms of nitrogen were present.
4. On very acid soils more nitrate nitrogen was used; on soils which approached neutral more ammonia nitrogen was used.

The preference of young cotton plants for ammonia nitrogen was tested in 59 field experiments (24) in which sulphate of ammonia and nitrate of soda were applied under cotton, and both treatments were side dressed with nitrate of soda. Using sulphate of ammonia under cotton and nitrate of soda as a side dressing produced an average of 31 pounds of seed cotton per acre more than applying nitrate of soda under and side dressing with nitrate of soda.

The author has observed that corn grows off much more rapidly where sulphate of ammonia is applied before planting than where nitrate of soda is applied before planting. It should be pointed out that nitrogen used as a side dressing for corn is usually more efficient than nitrogen applied before planting.

That soda has a commercial value for the production of certain crops has been well established. A few of the crops which are known to respond to soda are cotton, sugar beets, table beets, turnips, celery, mangels, Swiss chard, cabbage, tomatoes, spinach, and rutabagas. The extent to which deficiencies of soda for crops occur in soils is not well known.

Few data have been reported on tests in which soda has been tested directly. Most of the information has been derived from nitrogen sources tests. In a few cases table salt has been used in tests. The

general need of crops for soda is not considered in the evaluation of soda which follows.

The response of crops to soda has been attributed to (1) a direct nutrient response to soda, and (2) where nitrate of soda is the source of the sodium, to the soda (a) reducing the loss of potash by leaching, (b) reducing the loss of calcium and magnesium by leaching and (c) increasing the availability of the phosphorus. Table salt will supply sodium for plant nutrition; however, it probably does not reduce the loss of potash, calcium, and magnesium by leaching, and it has not been shown that it increases the availability of the phosphorus. Nevertheless, certain theoretical considerations suggest that table salt applied in the drill with phosphate may also increase the availability of the phosphorus.

Soda may be supplied to crops by (a) nitrate of soda, (b) table salt, and (c) the table salt in manure salts, which also contains about 25% potash. The commercial value of the soda in nitrate of soda may be calculated from the cost of obtaining the soda from table salt and manure salts.

Since the soda in nitrate of soda balances the nitrogen and maintains or slightly increases the total bases in the soil, the calculations showing the commercial value of the soda in nitrate of soda should also show the value of soda for neutralizing the nitrogen. The latter value should be in terms of limestone or dolomite, which are the materials most often used for correcting soil acidity.

The nitrogen in nitrate of soda and that in ammonium nitrate are considered to be of equal crop producing value. In the calculations below, the following costs were used:

(a) Table salt $15.00 per ton.
(b) Limestone (90% lime) applied to the land $6.00 per ton.
(c) Manure salts (25% potash) $30.00 per ton.
(d) Muriate of potash (60% potash) $50.00 per ton.

One ton of nitrate of soda supplies the same amount of nitrogen and soda and has the same effect on the soil as 1,000 pounds of ammonium nitrate, 1,375 pounds of table salt, and 1,269 pounds of lime. The cost of the table salt with the above prices is $10.31 and the cost of the lime is $3.81, which gives a total value of the soda in one ton of nitrate of soda of $3.81 plus $10.31 or $14.12. Expressed in other words, $14.12 more can be paid for one ton of nitrate of soda than for 1/2 ton of ammonium nitrate. With ammonium nitrate at $54.00 per ton, nitrate of soda has a value of $42.12 per ton where soda is needed.

The following two combinations of materials supply the same amount of nitrogen and soda and have the same effect on the total base content of the soil:

		Cost
A.	2,000 pounds of nitrate of soda	. . . . . .
	1,042 pounds of 60% muriate of potash	$26.05
B.	1,000 pounds of ammonium nitrate	. . . . . .
	2,500 pounds of 25% manure salts	37.50
	1,269 pounds of lime	3.81
	Total	$41.31

On the basis of the above tabulations, the soda in one ton of nitrate of soda is worth $41.31—$26.05 or $15.26. With ammonium nitrate at $54.00 per ton, nitrate of soda has a value of $28.00 plus $15.26 or $43.26 per ton where soda is needed by crops.

On the basis of the above assumed prices, the commercial value of the soda in one ton of nitrate of soda is $14 to $15 for crops growing on soils deficient in sodium. The local cost of materials which contain sodium may be used to calculate the local commercial value of the sodium in nitrate of soda, or manure salts.

Differences in the cost and in the physical properties of sources of nitrogen may be sufficient to offset small differences in efficiency. World War II stimulated the production of ammonium nitrate, and improvement of its handling properties. At the present time ammonium nitrate sold for fertilizer has reasonably good physical properties for direct application, and at the same time it is one of the cheapest sources of nitrogen available. The present cost of one pound of nitrogen is about 9 cents per pound in ammonium nitrate as compared to 16 cents in nitrate of soda. With the present differential in price of these two sources of nitrogen, unless soda is needed, ammonium nitrate is the cheapest source of nitrogen.

Sulphate of ammonia is suitable for use in mixed fertilizers in any desired quantity without impairing their physical properties, while only limited quantities of nitrate of soda, ammonium nitrate, or uramon can be used without obtaining fertilizers of poor handling properties.

SUMMARY AND CONCLUSIONS

The primary sources of nitrogen used as such are nitrate of soda, sulphate of ammonia, cyanamid, and ammonium nitrate. Other sources of nitrogen have appeared on the market from time to time,

but they are little used at present. So long as the nitrogen in different materials is present in the nitrate or the ammonium form, it should have equal value for crop production; however, other elements which are combined with the nitrogen influence the response of crops to the material.

The sources of nitrogen in mixed fertilizer are primarily sulphate of ammonia, urea, ammonium nitrate, and ammonia used in the ammoniation of superphosphate.

The experimental data on crop response to sources of nitrogen show that:

1. Crop yields decreased over a period of years where acid sources of nitrogen were used.
2. The use of lime with acid sources of nitrogen overcame the harmful effect of the acidity produced.
3. The requirement of cotton for superphosphate and muriate of potash increased in a few years where sulphate of ammonia was used without lime.
4. The requirement of cotton for superphosphate and muriate of potash decreased over a period of years where nitrate of soda was used as a source of nitrogen.
5. The yield of cotton produced with sulphate of ammonia and dolomite was less than the yield produced with nitrate of soda.
6. On soils low in phosphate and potash, nitrate of soda was superior to all other sources of nitrogen for cotton production, even though superphosphate and muriate of potash were applied.
7. One-half of the nitrogen applied to cotton as a side dressing after the crop was worked out was considerably more profitable than applying all of it before planting, in most tests.
8. Nitrogen used for corn after the corn was knee high produced larger yields than when it was applied at other stages of growth.
9. Nitrogen applied to oats as a top-dressing in March was slightly superior to other dates of application.
10. Based on average crop response, nitrate of soda did not leach out of the soil any more than other sources of nitrogen.
11. Dolomite usually increased the yield of cotton when acid sources of nitrogen were used; dolomite did not increase the yield when nitrate of soda was used as the source of nitrogen.
12. Natural organic sources of nitrogen are too expensive to use for fertilizer.
13. Seedling plants prefer ammonia nitrogen; old plants prefer nitrate nitrogen.

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(2)

Anhydrous Ammonia
Aqua Ammonia
Ammonium Nitrate in Solution
Solutions of Ammonium Nitrate and Urea
Solutions of Free Ammonia and Ammonium Nitrate or Urea

The Cheapest Sources of Nitrogen are in Liquid Form

Most nitrogeneous fertilizers are made from anhydrous ammonia. Anhydrous ammonia may be applied directly to the soil or it may be converted into aqua ammonia, ammonium nitrate, urea or other sources of nitrogen. Anhydrous ammonia, aqua ammonia, and mixtures of aqua ammonia and ammonium nitrate or urea are used for supplying a large part of the nitrogen in mixed fertilizers. Any of these may be used for direct application. The choice among them depends upon their cost, method of application, and their corrosiveness to tanks.

Attempts were made to use aqua ammonia in the 1850's in Europe. Apparently the equipment for handling and applying aqua ammonia was not suitable at that time. The first use of anhydrous ammonia for direct application was made at the Mississippi Delta Branch Experiment Station in 1930 (Fig. 1). A small cylinder of anhydrous ammonia was attached to a plow from which a tube conducted the ammonia into the soil.

The application of anhydrous ammonia in irrigation water was started in California in the early thirties, by the Shell Development Company, who hold patent No. 2,285,932, 1942, for applying it directly to the soil. However, the practice did not develop before the work of Mississippi Agricultural Experiment Station was reported in 1947.
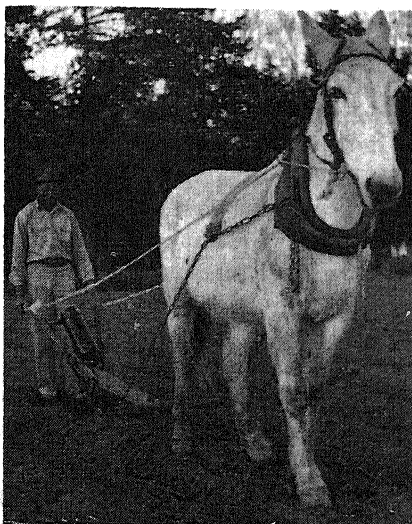
FIG. 1.—Anhydrous ammonia was first applied with a grey mule in 1930. (Courtesy J. O. Smith, Greenville, Miss.)

The Mississippi Agricultural Experiment Station started work on the use of aqua ammonia in 1943 and on anhydrous ammonia in 1944. After data had been obtained on the value of anhydrous ammonia for crop production and equipment had been developed for its application to the soil, the information was released to farmers in March of 1947. The anhydrous ammonia used in Mississippi is as follows:

1947 (spring)	2,253 tons
1947–1948	12,873 tons
1948–1949	27,433 tons
1949–1950	29,862 tons
1950–1951	26,240 tons
1951–1952	32,805 tons

By 1953 there were bulk stations for distributing anhydrous ammonia in 36 states, Cuba, Hawaii, Mexico, Norway, Puerto Rico, and Sweden, and it was being experimented with in other countries. It was estimated that anhydrous ammonia would supply about 30 per cent of the nitrogen used as materials in the 1952-1953 fertilizer year. To 1953, the development in the use of anhydrous ammonia had taken place with a shortage of both anhydrous ammonia and steel for handling it. When there are plentiful supplies of steel and anhydrous ammonia, and of other sources of nitrogen also, the competitive position of anhydrous ammonia will be established.

Work on the use of ammonium nitrate in solution was started in

some ammonium nitrate in solution, free ammonia and ammonium nitrate in solution, and a mixture of urea and ammonium nitrate in solution became available for direct application.

The cost of nitrogenous fertilizers in solution is less than that of bagged nitrogenous fertilizers. Though the retail price of sources of nitrogen in liquid form may not yet (1953) have become competitive, the probable order of increasing cost is: anhydrous ammonia, aqua ammonia, free ammonia and ammonium nitrate or urea, and ammonium nitrate or ammonium nitrate and urea.

PROPERTIES OF NITROGENOUS FERTILIZERS IN LIQUID FORM

The properties of nitrogenous fertilizers in liquid form determine the kind of storage containers required and dictate the methods of application to the soil.

Anhydrous ammonia contains 82 per cent nitrogen. It weighs 5 pounds and contains 4.1 pounds of nitrogen per gallon at 80° F. At lower temperatures it weighs slightly more and at higher temperatures slightly less. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. At 28° F. below zero and lower it is a liquid. Anhydrous ammonia has a gauge pressure of 75 pounds per square inch at 50° and 197 pounds at 100° F. When liquid anhydrous ammonia is run into an open container, depending upon its temperature, up to one-third of it evaporates. The heat lost in evaporation cools the remaining liquid to 28° F. below zero. Fittings may be replaced when the pressure has been lowered to atmospheric pressure by bleeding off vapor, even though a considerable quantity of liquid ammonia is still in the tank.

Anhydrous ammonia contains over 99 per cent ammonia. A general idea of purity may be obtained by collecting a quart jar full of anhydrous ammonia and permitting it to evaporate. To prevent water in the air from condensing in the ammonia the jar should be covered with a top containing holes. Evaporation is faster when the jar is set in a shallow pan of water. When the ammonia stops boiling, the water containing 25 to 30 per cent ammonia should be present only in the depressions in the bottom of the jar. If any significant amount of water is present dilution is indicated. However, the author knows of no anhydrous ammonia which was diluted.

In low concentrations ammonia is very irritating to the nose, eyes, mouth, throat and lungs. It blisters the skin. In high concentrations ammonia is deadly. Water, goggles, rubber gloves, and an acceptable first-aid kit should always be available. Any ammonia

which comes in contact with the body should be washed off immediately. If ammonia should get into one's eye it should be washed out immediately. There have been few accidents in handling anhydrous ammonia for direct application to the soil because the equipment is good and care has been used in handling it.

Anhydrous ammonia is handled as a liquid under pressure. It is stored in tanks which have a working pressure of 250 pounds per square inch, or a lower pressure if refrigerated. The information now available suggests that the atmospheric temperature may not get high enough for large tanks to pop off provided the pop valve begins to operate at about 240 pounds of pressure per square inch. All equipment except hose should be made of steel. The hose should be resistant to ammonia. Since brass and bronze are attacked by ammonia, they are not suitable for use in anhydrous ammonia fittings.

Anhydrous ammonia is not very explosive; however, air containing 16 to 25 per cent ammonia may be ignited by a spark, causing an explosion. *Openings in tanks which contain a mixture of air and ammonia should not be welded, because of explosion hazards.* Anhydrous ammonia is much lighter than air and rises quickly unless brought down by wind. In agriculture, where it is handled outside of buildings, it is not likely that there will be a combination of circumstances required for an explosion.

A very poisonous gas (hydrocyanic acid) is formed when a mixture of ammonia and fuel gases burns. For this reason, anhydrous ammonia should not be put into tanks which are to be used for butane or propane for heating buildings which are occupied; else special care should be used to remove the ammonia before fuel is put into the tank. The ammonia may be removed by air or water. The absence of the odor suggests that all of the ammonia has been removed. However, *a competent authority should be consulted before a layman puts fuel gas into a tank previously used for anhydrous ammonia.*

Many states have laws to establish and enforce reasonable rules and regulations concerning specifications of equipment and methods of handling anhydrous ammonia. In general, anhydrous ammonia bulk storage should be placed outside of cities and towns, and at a safe distance from regularly inhabited buildings, because there is always a possibility of an accident.

Aqua ammonia is made by diluting anhydrous ammonia with water. The approximate relation between the starting temperature of the anhydrous ammonia and water to the percentage of ammonia which can be readily absorbed is shown in Table 1[1]. For each per cent

[1]The calculations were made from data presented in "Ammonia—Its Uses and Properties". The Commercial Solvents Corporation. New York, N. Y.

of ammonia put into the final mixture the temperature is raised about 3.4° F.

The rise in temperature may be used as a measure of the amount of ammonia put into a known quantity of water. Subtracting the percentage of ammonia from 100 gives the pounds of water in 100 pounds of the mixture. Where the starting temperature of the ammonia and water is 70° F., 20 pounds of ammonia may be absorbed in 80 pounds of water, which gives 20 per cent ammonia in the mixture. The temperature of this mixture increases to 137° F. With higher ammonia and water temperatures less ammonia is absorbed; with lower temperatures more ammonia is absorbed.

Table 1.—DILUTION OF LIQUID ANHYDROUS AMMONIA TO AQUA AMMONIA AS AFFECTED BY TEMPERATURE AT ATMOSPHERIC PRESSURE—APPROXIMATE VALUES.

Per cent ammonia by weight	Increase in temperature degrees F.	Maximum water and ammonia temperature degrees F.	Final temperature degrees F.
10	34	161	195
12	41	144	185
14	48	122	170
16	54	110	164
18	61	89	150
20	67	70	137
22	72	50	122
24	78	32	110

For on-the-farm dilution it is suggested that the concentration of ammonia be limited to about 4 per cent less than the maximum indicated in Table 1. Liquid ammonia should be used for dilution, because the extra heat given off in the absorption of ammonia gas markedly reduces the amount of ammonia which is absorbed. If sufficient ammonia is added to raise the pressure above atmospheric pressure, the pressure will be reduced when the mixture cools. Running water over the tank speeds up cooling.

The dilution of anhydrous ammonia should be carried out in tanks which have a working pressure of as much as 50 pounds per square inch. The tank should be provided with a pressure gauge, pop-off valve and air inlet valve. The tank should be closed during dilution to prevent the escape of ammonia into the air. The liquid ammonia should enter the diluting tank through a pipe drilled with small holes, which should extend the length of the tank.

Ammonia combines with clay and organic matter to form solids. When anhydrous ammonia is applied to the soil it goes into solution, forming aqua ammonia which diffuses until it comes in contact with

sufficient clay and organic matter to hold it, after which it does not move. In tests on a sandy loam soil, in which 100 pounds of nitrogen per acre was applied in 42-inch rows, ammonia moved until it came in contact with a cross section of about 16 square inches of soil (Fig. 2). The area covered is larger in more sandy soils and smaller in soils containing more clay. Ammonia and other forms of nitrogen move only a little laterally. In order to get nitrogen it is necessary for plants to grow roots to the point of application or to some lower depth where it may have leached to after being converted into the nitrate form.
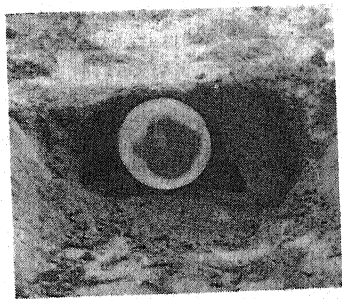
FIG. 2.—Anhydrous ammonia and other fertilizers do not move laterally. 122 pounds of anhydrous ammonia per acre in 42-inch rows covered a cross section of about 16 square inches in a sandy loam soil. (Courtesy Mississippi Agricultural Experiment Station.)

Soil microorganisms should be increased by the application of anhydrous ammonia because crop residues, on which they live, are increased by anhydrous ammonia. For a short time after application soil microorganisms are decreased in the small volume of soil affected by the ammonia. After the ammonia is changed to nitrates, which takes only about six weeks in the spring of the year, or used by plants, the soil microorganisms re-invade the affected soil almost instantaneously because many of them may double their numbers in less than an hour. The food supply determines the number of microorganisms in the soil.

Earthworms are, no doubt, killed by anhydrous ammonia in the affected zone. However, they should re-invade this zone as soon as the ammonia is changed into nitrates or used by plants. The increase in crop residues produced by anhydrous ammonia or other fertilizers should increase earthworms and other similar organisms because crop residues are their food.

The soil may be cultivated where anhydrous ammonia has been applied when the odor of ammonia is no longer observable at the

point where it was released. When the odor of ammonia is no longer present it has been converted into solids and will not be released when exposed to the air. After anhydrous ammonia has been applied for 24 hours it may be plowed up in most cases.

Ammonium nitrogen does not leach out of the soil. However, ammonia is a non-leaching source of nitrogen for only a short time after application. During warm weather ammonia is changed into nitrates in three to six weeks. In cold weather more time is required. In strongly acid soils (below pH 5.0) the rate of change of ammonia into nitrate nitrogen is very slow, and anhydrous ammonia applied after the first frost in the fall is carried through the winter and nitrifies in time for fall-planted small grains to utilize it in the spring. However, *under most conditions the non-leaching life of nitrogen applied as ammonia is short.*

Nitrogen may be lost into the air when heavy soils are saturated with water. Under these conditions the air may almost be eliminated, and soil microorganisms use oxygen combined with nitrate nitrogen, releasing gaseous nitrogen into the air. On heavy soils, which remain saturated during the winter and early spring, the loss of nitrogen by this means may be significant.

Nitrification of ammonia is brought about by soil microorganisms. With freezing temperatures there is no conversion of ammonia into nitrates. Nitrification is rapid at 80 to 90° F., and is slow at 60°, but some nitrification takes place below 50°. It is probable that the conversion of ammonia into nitrates parallels the growth of small grains and corn. When it is too cold for small grains to grow, little nitrification takes place. Both the growth of small grains and nitrification increase as the weather warms up, and both are rapid in the late spring. The most rapid period of nitrification, no doubt, is when corn is growing most rapidly.

Anhydrous ammonia must be applied and covered simultaneously to prevent its loss into the air. The explosiveness with which it evaporates encourages farmers to do a good job of application. Because of the evaporation of ammonia into the air and the burning of plants, it is impracticable to apply anhydrous (or aqua) ammonia in sprinkler irrigation systems.

Anhydrous (or aqua) ammonia may be applied in surface irrigation water; however, the soil nearest to where the water enters the field absorbs more ammonia and less is available as the distance increases. Where part of an area being irrigated is more sandy, or for some other reason more water goes into the soil, it gets more nitrogen than the rest of the field. Consequently the distribution of nitrogen is not

uniform and ripening of some crops may be uneven. Uneveness in ripening of crops like rice, which are combined, is not desirable; however, variation in the rate of application of nitrogen to crops like corn is of little importance from the standpoint of effect on ripening. In hot or windy weather a considerable amount of ammonia may be lost into the air from irrigation water.

Aqua ammonia contains up to 30 per cent ammonia, which is equal to 24.6 per cent nitrogen and 70 per cent water. Aqua ammonia containing 30 per cent ammonia exerts no pressure below 70° F. and only a slight pressure above this temperature. It weighs 7.4 pounds and contains 1.85 pounds of nitrogen per gallon. All equipment for handling and storing aqua ammonia should be made of iron or steel and ammonia-resistant hose. Tanks should have both a pop-off valve and an air-inlet valve. Copper and brass fittings are readily attacked by aqua ammonia.

Aqua ammonia must be applied and covered simultaneously to prevent the loss of ammonia, just as is necessary with anhydrous ammonia. Because of the failure of the ammonia to evaporate conspicuously, the author has observed that good farmers may store aqua ammonia in tanks from which it evaporates, and that in application they may cover it so poorly that a large percentage of the ammonia evaporates into the air. Even though aqua ammonia may be stored and applied so that little ammonia is lost, the author has observed that most farmers handle aqua ammonia so that a large percentage of the ammonia is lost. Most of the farmers who used aqua ammonia in Mississippi during the late forties have since changed to anhydrous ammonia. Farmers have been known to apply aqua ammonia without any immediate covering, and even on frozen ground where covering was not intended.

Ammonium nitrate in solution contains about 60 per cent ammonium nitrate, which contains 21 per cent nitrogen. With a higher concentration ammonium nitrate salts out during cold weather. This solution may be applied on the surface of the land or sprayed on certain crops. Ammonium nitrate in solution is not corrosive to aluminum, but it is corrosive to iron and steel.

Solutions of ammonium nitrate and aqua ammonia contain 36 to 45 per cent nitrogen. The ammonium nitrate is corrosive and the aqua (free ammonia) evaporates like that in aqua ammonia. This solution must be applied in the soil and covered simultaneously to prevent the loss of the free ammonia into the air, just as is necessary with anhydrous and aqua ammonia. These solutions corrode metals, though more slowly than ammonium nitrate alone.

Since solutions of ammonium nitrate and ammonia must be applied and covered with as much care as is necessary with anhydrous ammonia and they are both more expensive and corrosive, it is doubtful if they can compete. However, where these solutions are used in making mixed fertilizers, a limited quantity may be marketed for direct application.

The ammonium nitrate and aqua ammonia solutions usually contain about one-half of their nitrogen as ammonium nitrate and one-half as free ammonia; however, the ratio varies. When the percentage of ammonium nitrate is high it may salt out during cold weather. These solutions develop little or no pressure, depending upon the percentage of free ammonia.

Solutions of urea and aqua ammonia contain 36 to 45 per cent nitrogen. These solutions must be applied and covered simultaneously to prevent the loss of the free ammonia into the air. These solutions are more expensive than anhydrous ammonia; however, storage equipment is less expensive because there is little or no pressure. They are not corrosive to iron and steel. They develop little or no pressure, depending upon the percentage of free ammonia. Since fertilizer mixers use solutions of aqua ammonia and urea in mixed fertilizers they may sell a limited amount of nitrogen in this form for direct application. It is doubtful if these solutions can compete with anhydrous ammonia.

Solutions of ammonium nitrate and urea for direct application contain about 32 per cent nitrogen. The ammonium nitrate in this solution is corrosive to iron and steel, as discussed above. Like ammonium nitrate, this solution may be applied on the surface of the land or sprayed on some crops. No doubt, some form of 2,4-D may be used in this solution for weed control.

The properties of the nitrogenous fertilizers in liquid form are summarized as follows:

Solutions which must be applied and covered simultaneously	Solutions which may be applied without covering
Anhydrous ammonia	Ammonium nitrate
Aqua ammonia	Urea and ammonium nitrate
Ammonium nitrate and aqua ammonia	
Urea and aqua ammonia	

Solutions not corrosive to iron and steel	Solutions corrosive to iron and steel
Anhydrous ammonia	Ammonium nitrate

Aqua ammonia
Aqua ammonia and urea

Ammonium nitrate and aqua
  ammonia
Ammonium nitrate and urea

All of the nitrogenous fertilizers in liquid form are slightly acid forming. In order to maintain the lime content of the soil it is necessary to apply about two pounds of agricultural lime per pound of nitrogen applied in these solutions, which is the lime required where ammonium nitrate is applied. Rather than apply lime annually to offset the acidity of fertilizers, it is more practicable to apply the needed lime at intervals of five to ten years.

CROP RESPONSE TO NITROGENEOUS FERTILIZERS IN LIQUID FORM

Data are presented below on the response of several crops to anhydrous ammonia as compared to solid ammonium nitrate, and on the response of oats to ammonium nitrate in solution, with and without 2,4-D for weed control, as compared to solid ammonium nitrate.

Plants grow roots to the nitrogen in the soil. None of the nitrogenous fertilizers move laterally in the soil to any significant extent. Most movement of nitrogen is downward; on very heavy soils it may be carried off in surface water in the nitrate form. A very small amount of nitrate nitrogen may accumulate at the surface of the soil during dry weather.

Nitrogen should be placed close to slow-growing plants like cotton if they are to respond to it in a short time. Where soils have a fair supply of residual nitrogen in organic matter, nitrogen may be placed farther away from the plants without reducing the yield. If plants are to use nitrogen soon after application as a side dressing it should be applied at the edge of the root zone.

Fast-growing crops like corn may be side dressed half way between the rows or at any position relative to the plants, as far as total yield is concerned. However, they grow off more rapidly if the nitrogen is placed relatively close to the young plants.

ANHYDROUS AMMONIA

Anhydrous ammonia is slightly superior to ammonium nitrate for cotton production (2)[1] when applied before planting. As an average of 31 tests conducted in Mississippi, anhydrous ammonia made 38 pounds of seed cotton per acre more than ammonium nitrate (Table 2).

[1]Numbers in parenthesis refer to the references on page 75. The data reported in this chapter are from Mississippi Agricultural Experiment Station Bulletin No. 482, 1952, unless otherwise indicated

The depth of application was four inches. The slight superiority of anhydrous ammonia is attributed to less leaching during the first few weeks after application.

A six-inch depth of placement of anhydrous ammonia produced an average of 39 pounds more seed cotton than a four-inch depth in 18 tests when applied before planting. It should be pointed out that

Table 2.—THE RESPONSE OF COTTON TO ANHYDROUS AMMONIA AND AMMONIUM NITRATE

Pounds nitrogen per acre	Time of application	Source of nitrogen		Anhydrous ammonia
		Ammonium nitrate		
		Surface	4–5" deep	4–5" deep
	Increase in yield, lbs. seed cotton per acre			
		Average of 10 tests—dry year		
32	Early side dress	154	—	217
		Average of 31 tests		
64	Preplant	—	442	472
32	Preplant	—	297	344
		Average	370	408
32	Early side dress	280	325	281
		Average of 13 tests		
32	May side dress	260	343	261
32	June side dress	277	352	276

anhydrous ammonia is more easily sealed in the soil when applied six inches deep than at shallower depths.

Anhydrous ammonia was slightly superior to ammonium nitrate, cyanamid, nitrate of soda and sulphate of ammonia for cotton production in six tests in the Mississippi Delta. The increases in yield of seed cotton were: anhydrous ammonia 542, ammonium nitrate 530, nitrate of soda 518, sulphate of ammonia 500, and cyanamid 489 pounds of seed cotton per acre. The data are averages for 30, 45, and 60 pounds of nitrogen per acre. The slight superiority of anhydrous ammonia to sources which contain nitrate nitrogen is attributed to less leaching during the first few weeks after application.

Broadcast application of ammonium nitrate is as efficient as drilled application for cotton production. As an average of 21 tests broadcast application of ammonium nitrate increased the yield 313 pounds of seed cotton per acre as compared to 329 pounds for drilled

application. The rate of application was 32 pounds of nitrogen per acre. Where heavy lands are prepared during the fall and winter for spring-planted crops, broadcast application of ammonium nitrate just before planting should be satisfactory. This method of application could stimulate the growth of grasses more than deeper application. However, drilled applications of phosphorous and potash are usually more effective than broadcast applications.

Ammonium nitrate was superior to anhydrous ammonia for side-dressing cotton when both were placed four or five inches deep. As an average of 31 tests applied as an early side dressing, ammonium nitrate increased the yield 325 pounds of seed cotton per acre, and anhydrous ammonia 281 pounds. The superiority of ammonium nitrate as a side dressing is attributed to the preference of cotton at this stage of growth for nitrate nitrogen.

When moisture was adequate ammonium nitrate applied on the surface and anhydrous ammonia applied four to five inches deep as side dressings produced identical increases in yield of seed cotton. In 1944, when rainfall was very low, anhydrous ammonia applied five inches deep was much superior to ammonium nitrate applied on the surface, which emphasizes the need for applying fertilizers in the root zone when dry weather is likely to follow. An examination of the weather records for Mississippi suggests that surface applications of nitrogen to crops in May or later are likely to be much less effective than deeper applications in one-third of the years, because of dry weather. No doubt, deep application of nitrogen is much more effective than surface application in dry climates.

Early and late side dressing of cotton with both anhydrous ammonia and ammonium nitrate were equally effective. The early side dressing was applied soon after the cotton was chopped out and the late application about a month later. Applications of nitrogen in July are usually much less effective than when applied by the middle of June, but good increases in yield may be obtained from July applications. It is doubtful if July applications of nitrogen are effective where insects are destructive; however, where insects are controlled very late applications of nitrogen may give good increases in yield, even though they might have been more effective applied at an earlier date.

Anhydrous ammonia should be applied so that it does not come in contact with banded applications of superphosphate (unpublished data from Mississippi). In three tests, where the treatment was 60 pounds of nitrogen, phosphate and potash per acre, placing the anhydrous ammonia in contact with the superphosphate and muriate of potash

reduced the average yield of seed cotton 86 pounds per acre as compared to separating them.

In three other tests with 60 pounds of nitrogen, 20 pounds of phosphate and 50 pounds of potash per acre, the average reduction in yield was 211 pounds of seed cotton for putting them together as compared to separating them. In the latter tests 20 pounds of phosphate was apparently sufficient; and where 40 or 60 pounds was used, applying the ammonia with the phosphate and potash did not reduce the yield. In one test on an alkaline clay soil there was no reduction in yield at any of three rates of phosphate.

When anhydrous ammonia is applied in contact with superphosphate, no doubt, the water-soluble phosphorus is converted into less soluble forms, as takes place when superphosphate is treated with anhydrous ammonia. The data on page 288 show that ammoniation of 20 per cent superphosphate with an average of 4.78 per cent ammonia reduced its value to less than one-half that of untreated superphosphate.

The reduction in yield obtained for placing anhydrous ammonia in contact with superphosphate would also take place with aqua ammonia or solutions of aqua ammonia and ammonium nitrate or urea.

The fumes of anhydrous ammonia burn the leaves of plants, and may completely kill young plants like cotton. In most cases the injury is outgrown in a short time.

When seed come in contact with a large concentration of ammonia or most other fertilizers they are killed. Placement of the fertilizers too close below the seed may result in the young plants being killed after germination (Fig. 3). *For most applications, it is recommended that anhydrous ammonia be applied 5 to 6 inches to the side of where the seed are to be placed, or at the same position soon after planting.*

Anhydrous ammonia may rise high enough to damage seed even though the point of release is six inches deep when it is being applied by an applicator which cuts a smooth opening in the soil, and the opening is closed only at the top. It is recommended that a disk hiller or other covering device be placed next to the applicator in

FIG. 3.—Anhydrous ammonia and most other fertilizers damage seed and seedlings when placed too close to them. Anhydrous ammonia produced the injury shown on the left. (Courtesy Mississippi Agricultural Experiment Station.)

such a position that the ammonia is trapped at the point of release in the soil.

The time of application of nitrogen to cotton may be influenced by the grass and weed problem. Since nitrogen makes weeds and grass, as well as crops, grow it may be desirable to delay application of the nitrogen until the crop is cleaned out even though earlier

Table 3.—The Influence of Time of Application of Anhydrous Ammonia and Ammonium Nitrate, Applied at the Rate of 60 Pounds of Nitrogen per Acre, on the Yield of Cotton

Time of application	Sandy loam soil, 1949–1950			Clay soil, 1950	
	Test 1	Test 2		Test 3	
	Anhydrous ammonia	Anhydrous ammonia	Ammonium nitrate	Anhydrous ammonia	Ammonium nitrate
	Increase in yield, lbs. seed cotton per acre				
December (preplant)	752	568	462	315	372
May (preplant)	716	585	624	319	727
June (side dress)	626	—	—	—	—
July (side dress)	485	—	—	—	—

application might have been more effective in the absence of a weed and grass problem.

Fall and winter application of anhydrous ammonia and ammonium nitrate for summer crops is often much less effective than spring application (Table 3). In two tests on sandy loam soils December application of anhydrous ammonia was as effective as May application. In one test on sandy loam and in one on clay soil May application of ammonium nitrate was superior to December application. On the clay soil both ammonium nitrate and anhydrous ammonia applied in December were much less effective than May application of ammonium nitrate, which is attributed to both leaching and consumption of nitrogen by weeds and grass. The low increase in yield from anhydrous ammonia applied in May on the heavy soil was attributed to observable loss of ammonia in application.

The yield of corn was reduced eight bushels per acre by December application of both anhydrous ammonia and ammonium nitrate as compared to April application in one test. The rate of application was 120 pounds of nitrogen per acre and the top increase was 40 bushels. The difference may have been greater if conditions had been favorable for higher yields.

Data are presented below which show that the application of anhydrous ammonia as late as the last week in November is too early

for oats; which suggests that winter application is entirely too early for corn, cotton and other row crops in Mississippi.

Anhydrous ammonia has been superior to ammonium nitrate for corn production when applied before planting (Table 4). The difference was 5.5 bushels per acre in favor of anhydrous ammonia applied before planting at the rate of 100 pounds of nitrogen per acre, as an average of 11 tests.

Table 4.—THE RESPONSE OF CORN TO ANHYDROUS AMMONIA AND AMMONIUM NITRATE

Pounds nitrogen per acre	Time of application	Source of nitrogen		
		Ammonium nitrate		Anhydrous ammonia
		Surface	4–5'' deep	4–5'' deep
	Increase in yield, bu. corn per acre			
		Average of 7 tests—dry year		
32	Early side dress	7	—	10
		Average of 5 tests		
32	Early side dress	12	12	15
32	Preplant	—	12	13
		Average of 13 tests		
32	Side dress	14	15	17
		Average of 11 tests		
100	Preplant	—	36	41
100	Early side dress	40	40	40
100	Late side dress	41	44	43
200	Preplant	—	50	52

When applied as a side dressing, anhydrous ammonia and ammonium nitrate have made almost identical increases in yield of corn. There was very little difference in the yield of corn where anhydrous ammonia was applied before planting, as an early side dressing, or as a late side dressing. *The increase in yield was approximately 40 bushels for 100 pounds of nitrogen per acre, a bushel of corn per 2½ pounds of nitrogen.*

Surface-applied ammonium nitrate was much less efficient for corn than anhydrous ammonia or ammonium nitrate applied four or five inches deep when dry weather followed application (Table 4). Where a reasonable amount of rain fell after application, surface-applied ammonium nitrate was just as efficient as that applied in the soil. *Because of the possibility of dry weather in the summer, it is*

good insurance to apply any fertilizer used as a side dressing four or more inches deep.

Fall-planted oats apparently use ammonium and nitrate nitrogen equally well; however, in the spring they must have nitrate nitrogen for maximum growth. Normally, in the northern half of Mississippi, oats planted after October 15 make little growth before March regardless of the fertility of the soil. Small oats cannot store up much nitrogen in the fall and winter growth; fall-applied nitrogen, if it is to make a significant contribution to the yield of oats, must be carried through the winter in the soil. The winters in the South are warm enough most of the time for ammonia to be changed into nitrate nitrogen. Once nitrogen has been converted into the nitrate form it is subject to leaching.

Fall application of ammonium nitrate was unsatisfactory for oat production in all 10 tests conducted (Table 5). It was less effective on the less acid than on the strongly acid soils, which parallels the behavior of anhydrous ammonia. As was pointed out above, in North Mississippi late-October-planted oats make little growth before spring, and in order for fall-applied nitrogen to be utilized by them it must be carried through the winter in the soil.

Table 5.—THE EFFECT OF SOIL REACTION ON THE RESPONSE OF OATS TO FALL-APPLIED ANHYDROUS AMMONIA

Source of Nitrogen 32 pounds per acre	Time of application	Lime content of soil, test number									
		Low, pH 5.1 or less					High, pH 5.5 or higher				
		1	2	3	4	5	6	7	8	9	10
		Increase in yield, bu. of oats per acre									
Anhydrous ammonia	Fall	30	32	30	29	19	25	12	15	14	4
Ammonium nitrate	Spring	21	25	25	27	20	30	19	22	24	24
Ammonium nitrate	Fall	16	15	16	20	10	15	8	8	10	5

When applied during the third week in February anhydrous ammonia increased the yield of oats 20 bushels per acre as compared to 15 bushels for ammonium nitrate in six tests in which the rate of nitrogen was 32 pounds per acre. The data suggest that a considerable amount of the ammonium nitrate nitrogen leached out before the oats were able to utilize it. The data also suggest that nitrate nitrogen should not be applied to fall-planted small grains until the weather is warm enough for vigorous growth to begin.

The stand of small grains is not damaged materially by anhydrous ammonia applicator knives in top dressing. If the small grains are well rooted the applicator knives usually go between plants without uprooting them.

On soils which are low in lime anhydrous ammonia applied from the last of October until (possibly) February 15 is as effective for producing oats as ammonium nitrate applied the first of March. In five tests (32 pounds of nitrogen per acre) which were low in lime (pH 5.1 or less), anhydrous ammonia applied the last of October increased the yield 28 bushels of oats per acre as compared to 23 bushels for ammonium nitrate applied in March. On one soil (pH 4.95) aqua ammonia applied the last of January increased the yield 30 bushels as compared to 27 bushels for ammonium nitrate applied early in March.

On a soil which was low in lime (pH 5.1), anhydrous ammonia was not a satisfactory source of nitrogen for oats when applied in early March. When applied to this low-lime soil in early March the ammonia was changed into nitrate nitrogen so slowly that the increase in yield of oats was only 10 bushels per acre as compared to 19 bushels for fall-applied anhydrous ammonia and 20 bushels for spring-applied ammonium nitrate. The rate of application was 32 pounds of nitrogen per acre.

When applied the first of March on soils which are medium to low in lime, anhydrous ammonia is much less effective than ammonium nitrate for the production of oats. In an average of eleven tests applied the first of March anhydrous ammonia increased the yield of oats only 19 bushels as compared to 26 bushels per acre for ammonium nitrate.

On soils of medium to high lime content (pH 5.5 or higher) anhydrous ammonia applied the last of October increased the yield an average of only 13 bushels of oats per acre as compared to 23 bushels for ammonium nitrate applied the first of March (five tests). In three tests with 32 pounds of nitrogen per acre the following increases in yield of oats were obtained:

Date of application	Source of nitrogen	
	Anhydrous ammonia	Ammonium nitrate
	Increase in yield, bu. oats per acre	
Last of October................	5.6	
Last week in November........	12.4	
Third week in February........	21.3	16.9

The last week in November is too early to apply anhydrous ammonia to oats for grain. When applied during the third week in February anhydrous ammonia is superior to ammonium nitrate. Apparently

the third week in February is too early to apply ammonium nitrate to oats because of the leaching of the nitrate nitrogen.

On a high-lime soil (pH 7.8) anhydrous ammonia applied in March increased the yield 25 bushels of oats per acre as compared to 4 bushels for October-applied and 24 bushels for March-applied ammonium nitrate. The rate of change of ammonia into nitrate nitrogen was rapid in this soil and nitrate nitrogen was available to the oats in a short time after application as anhydrous ammonia in the spring; when applied in October anhydrous ammonia was converted into nitrate nitrogen and leached out of the soil during the winter.

Anhydrous ammonia applied the last of October in four tests increased the yield of oats only 7 bushels per acre as compared to 20 bushels per acre for application during the third week in February. The lime content of the soils was high enough for nitrification to take place during the winter months. Thirty-two pounds of nitrogen per acre was applied.

Fall-applied anhydrous ammonia was unsatisfactory for wheat in Indiana (6). The average increase in yield of wheat for three rates of nitrogen was as follows:

Source of Nitrogen	pH of soil in tests				
	4.8	4.8	5.5	6.5	6.7
	Increase in yield, bu. wheat per acre				
Ammonium nitrate—spring	5.1	11.4	11.9	8.3	8.0
Anhydrous ammonia—fall	4.0	9.5	8.4	4.3	3.0

Even on strongly acid soils anhydrous ammonia applied in the fall was less satisfactory than ammonium nitrate applied in the spring. The increase in yield for anhydrous ammonia applied in the fall on soils of pH 4.8, 4.8, 5.5, 6.5 and 6.7 was 1.1, 1.9, 3.5, 4.0 and 5.0 bushels less than where ammonium nitrate was applied in the spring.

The efficiency of fall-applied anhydrous ammonia for wheat in Indiana was similar to that for oats in Mississippi on strongly acid soils, though in Mississippi fall-applied anhydrous ammonia was equal to or superior to spring-applied ammonium nitrate. In both states fall-applied anhydrous ammonia was unsatisfactory on soils having a pH of 5.5 or higher.

In Indiana and Mississippi the fall-applied anhydrous ammonia was applied at about the same time, which suggests that soil reaction is a more important factor in nitrification of ammonia than the differences in fall and winter temperature.

In the Indiana experiments anhydrous ammonia applied in the spring and ammonium nitrate applied in the fall were unsatisfactory for wheat in all of the tests.

Fall application of anhydrous ammonia and sulphate of ammonia on fall-planted crops should have the same efficiency. Spring application of sulphate of ammonia was much superior to fall (drilled) application for wheat in Pennsylvania (5). When 20 pounds of nitrogen was applied at planting time, between September 15 and October 18, the average yield of 17 tests over a period of years was 4.6 bushels of wheat per acre less than where the nitrogen was applied in the spring. In six tests where 40 pounds of nitrogen was applied one month after sowing (freezing weather usually begins the last of November) the average yield was 4.8 bushels less than when applied in the spring. As an average of six tests, 20 pounds of nitrogen applied in the spring was superior to 40 pounds applied in the fall where good increases for nitrogen were obtained. *On the basis of the above data anhydrous ammonia applied in the fall would not be expected to go through the winter in a climate as cold as Pennsylvania.*

Unused nitrogen may increase the yield of the following crop, which increases the income from the use of nitrogen. The carry-over of the nitrogen from one crop to another is more often observed on heavy soils, particularly on heavy soils which have a clay pan. However, carry-over of some nitrogen may be obtained even though a considerable amount of nitrogen is leached out of the soil or is lost in the run-off water.

The application of anhydrous ammonia and other sources of nitrogen in the fall and winter for small grain production and for spring crops in any area should be made only after careful investigation. Nitrogen is generally deficient for most non-legume crops, and the response to it is large. When anhydrous ammonia is applied a considerable time before it is used by plants, none may be lost, all of it may be lost, or the loss may be between these extremes. Having the right amount of nitrogen available for crops when it is needed is so desirable that risks should not be taken with applications which are uncertain. *There is considerable value in an accurate appraisal of the quantity of nitrogen present for the crop, which is only possible when it is applied close to the time when it is used by the crop.*

The leaching of nitrogen is probably not serious in climates which have so little rainfall that most soils have sufficient lime for alfalfa. This, of course, would not apply to soils in high rainfall areas which are high in lime because they have developed from material which was high in lime. In dry climates nitrogen can possibly be applied

at any time without serious loss from leaching; however, under these conditions (when applied well in advance of its use by plants), its efficiency may be reduced by conversion into the organic form by microorganisms in the decomposition of low-nitrogen crop residues.

A reasonable spacing of anhydrous ammonia applicators for top dressing oats for grain is 24 inches. When anhydrous ammonia applicators are spaced farther apart than 16 inches a strip of oats down the middle usually fails to send roots to the place where the ammonia was applied and they do not get nitrogen. However, the oats which do get nitrogen grow more and largely make up the difference (Table 6).

Applicators spaced 24 inches apart shed trash more readily than when spaced closer, and a 24-inch spacing is recommended. On very wet and heavy soils oats may not grow roots to ammonia placed more than six inches away; however, though no data are available, it is not improbable that a good 12-inch band of oats every 24 inches will make about as much oats as uniform growth over the entire area.

Table 6.—THE EFFECT OF APPLICATOR SPACING ON THE RESPONSE OF OATS TO ANHYDROUS AMMONIA

Spacing of applicators inches	Pounds of nitrogen per acre			
	32	48	64	Average
	Increase in yield, bushels oats per acre			
16	23	21	29	24
24	22	18	28	23
36	21	18	24	21
No. of tests	6	2	4	12

Anhydrous ammonia and ammonium nitrate have been equal in value on oats for forage. As an average of 14 tests the following yields were obtained by the first of March:

Source of nitrogen	Yield—pounds air-dry forage per acre
None	648
Ammonium nitrate	1644
Anhydrous ammonia	1711

A spring application of nitrogen is necessary for the production of oats for grain even though a large quantity is applied to them for forage in the fall. When 96 pounds of nitrogen per acre, which is

much more than needed, was applied to oats for fall- and winter-forage production the yield of grain in the spring was only one bushel more than was produced with no clipping and no nitrogen in the fall or spring. Where nitrogen was applied in the fall and spring, clipped oats made 17 bushels more than where they were not clipped and received no nitrogen (9 tests).

Clipping oats for forage during the fall and winter reduced the average yield of grain five bushels per acre in nine tests. The clipped oats received nitrogen in both fall and spring; the unclipped oats received nitrogen only in the spring. In three tests the average reduction in yield was 19 bushels and the yield of forage was 1141 pounds; in the six tests where clipping did not reduce the grain yield the average yield of forage was 1726 pounds per acre.

Observations suggest that rank oats are easily winter killed. It is therefore suggested that oats and other small grains be grazed so that they are not permitted to get stemmy. If they are grazed too closely there is insufficient leaf area to make significant growth. It appears that they should be maintained at a height of four to five inches.

Anhydrous ammonia was superior to ammonium nitrate on an established stand of fescue and hop clover (Table 7). The increase in yield for 67 and 100 pounds of nitrogen, respectively, was 1113 and 2006 pounds of air-dry forage per acre for ammonium nitrate and 2665 and 3252 for anhydrous ammonia. The superiority of anhydrous ammonia is attributed to the fact that the soil below one inch had a pH of 4.9, which retarded nitrification and subsequent leaching of the nitrogen. The top inch of the soil had a pH of 6.2, which was conducive to nitrification of the ammonia in the ammonium nitrate,

Table 7.—The Response of Fescue and Hop Clover to Anhydrous Ammonia and Ammonium Nitrate

Source of nitrogen	Time, rate per acre		Applicator spacing inches	Air-dry yield, lbs. per acre			
	Sept.	Feb.		Feb. 14	April 8	May 21	Total
No nitrogen	—	—	—	345	572	1270	2187
Ammonium nitrate	33	—	—	551	846	1327	2724
Ammonium nitrate	33	33	—	593	1129	1416	3138
Ammonium nitrate	67	—	—	739	1138	1423	3300
Anhydrous ammonia	67	—	18	1020	2165	1667	4852
Ammonium nitrate	67	33	—	769	1694	1373	3836
Ammonium nitrate	100	—	—	1156	1611	1426	4193
Anhydrous ammonia	100	—	18	1319	2270	1850	5439
Anhydrous ammonia	100	—	27	1248	2042	1843	5133
Anhydrous ammonia	100	—	36	890	1987	1839	4716

making all of the nitrogen in the ammonium nitrate subject to leaching. With a pH of 6.2 in the top inch of soil there was a reasonable supply of calcium for the spring hop clover and the grasses.

Conservation of the ammonium form of nitrogen is promoted by strongly acid soils, as borne out by the above data on fescue and on oats. However, the pH should approach 7 to supply lime to many plants, to maintain phosphorus available, and to reduce the leaching of potash. These conditions may be obtained on strongly acid soils devoted to pastures and other sod crops by lightly liming the top soil after the crops are planted, and applying the ammonium form of nitrogen in the soil. With some other crops the conditions may also be obtained on strongly acid soils by applying a limited quantity of lime with or near the seed.

The nitrogen conserved by maintaining most of the soil strongly acid must be weighed against some sacrifice in the available phosphorus, and the possibility that maximum yields may not be produced under these conditions. However, the most profitable yields may be somewhat less than maximum yields.

On a silt loam soil, spacing anhydrous ammonia applicators 18 inches apart for fescue and clover produced 5439 pounds of air-dry forage as compared to 5133 and 4716 pounds for 27- and 36-inch spacings. A 24-inch spacing is suggested for most conditions.

The use of anhydrous ammonia on very poor land to be planted to fescue produces a narrow band of excellent fescue directly over the ammonia, and that in between sometimes dies. If a solid stand of fescue is desired a solid source of nitrogen should be used and applied uniformly at seeding time. Anhydrous ammonia may then be used for later applications.

The yield of sugarcane syrup was 617 gallons with anhydrous ammonia and 598 gallons per acre with ammonium nitrate, as an average of three comparisons in six tests. The rate of application was 60 pounds of nitrogen per acre. Split applications of nitrogen were not superior to one application before planting or as an early side dressing.

The yield of sorghum syrup with anhydrous ammonia was 318 gallons per acre as compared to 308 for ammonium nitrate, 311 for nitrate of soda, 310 for sulphate of ammonia, and 322 gallons for sulphate of ammonia and lime. The data are from two four-year tests, and nitrogen was applied at a rate of 48 pounds per acre.

Anhydrous ammonia compared favorably with ammonium nitrate for beans, cabbage, tomatoes and sweet potatoes (Table 8). The six-inch depth of application was superior for tomatoes. In order to

Table 8.—The Response of Truck Crops to Sources of Nitrogen

Sources of nitrogen	Depth of application	Crop, years of test, measure			
		Cabbage[1] 1	Tomatoes[1] 2	Beans[1] 2	S. potatoes[2] 2
		Yield per acre, obs. or bu.			
Ammonium nitrate	4	18,077	10,003	184	186
Anhydrous ammonia	4	18,513	8,272	180	183
Anhydrous ammonia	6	18,404	9,976	171	
Anhydrous ammonia	6[3]	18,513	8,727	176	
Nitrate of soda	4	18,186	9,763	152	184
Sulphate of ammonia	—	—	—	—	150

[1]72 pounds of nitrogen before planting and 32 pounds as a side dressing.
[2]48 pounds of nitrogen per acre.
[3]All nitrogen before planting.

avoid injury to young plants, a six-inch depth of application and placement about five inches to the side of the place where the seed or young plants are to be placed is suggested.

The application of anhydrous ammonia as a side dressing to short season truck crops three weeks earlier than is usual for nitrate of soda and ammonium nitrate is recommended. Many of these crops require nitrate nitrogen at side-dressing time. The earlier application is suggested to provide time for the ammonia to be converted into nitrate nitrogen. When anhydrous ammonia is applied close to planting time, no doubt only one application is necessary, which would save one trip over the land.

Anhydrous ammonia and ammonium nitrate produced equal increases in the yield of pasture forage in a season of normal rainfall (Table 9). The first application of nitrogen was made during the first part of July, which is too late for maximum response to nitrogen.

Table 9.—The Response of Pasture Grasses to Anhydrous Ammonia and Ammonium Nitrate in a Season of Normal Rainfall. Average of Five Tests

Source of application	Spacing of applicators	Pounds of nitrogen per acre	
		45	99
		Increase, lbs. dry forage	
Ammonium nitrate	Broadcast	768	1304
Anhydrous ammonia	16 inches	752	1328
Anhydrous ammonia	32 inches	714	1198
Yield without nitrogen		1392	

The increase in yield of air-dry pasture forage was essentially the

same for ammonium nitrate and anhydrous ammonia. With sufficient rainfall to carry the nitrogen applied as ammonium nitrate into the root zone, surface application of ammonium nitrate was as effective as anhydrous ammonia applied in the root zone, which contrasts sharply with the results reported below for a dry year. The difference between the 16- and 32-inch spacings of the anhydrous ammonia applicators was small.

Higher yields of Dallis grass pasture forage were produced by anhydrous ammonia applied in the root zone than by ammonium nitrate applied on the surface during a dry year (Table 10). Ammonium nitrate failed to make yields equal to those produced by anhydrous ammonia because of differences in placement. The anhydrous am-

Table 10.—THE RESPONSE OF PASTURE GRASSES TO ANHYDROUS AMMONIA AND AMMONIUM NITRATE IN A DRY YEAR—AVERAGE OF FIVE TESTS

Nitrogen		Pounds nitrogen per acre		
Source	Spacing	33	66	99
		Increase in yield, lbs. air-dry forage		
Ammonium nitrate	Broadcast	624	1094	1665
Anhydrous ammonia	16 inches	1053	1461	2014
Anhydrous ammonia	24 inches	——	1503	——
Yield without nitrogen		1692		

monia was placed in the soil where the plants could recover it. The nitrate part of the ammonium nitrate, no doubt, was leached into the soil by a small amount of rain; however, it is necessary for the ammonium part of the ammonium nitrate to be changed into the nitrate form before it can be leached into the root zone. Even though plants have active roots in the surface soil during periods of wet weather, feed roots, no doubt, disappear from the surface soil or become inactive during dry weather.

In one test in a relatively dry year anhydrous ammonia was much superior to ammonium nitrate for forage production by Dallis grass pasture:

Treatment, June 17 66 lbs. nitrogen per acre	Date of clipping				
	July 22	Aug. 23	Oct. 6	Total	Increase
Anhydrous ammonia, 4" deep	3085	981	1533	5599	3263
Ammonium nitrate, surface	1826	908	1114	3848	1512

The total rainfall for the duration of the test was only 8.3 inches

from June 17 to October 6. The placement of anhydrous ammonia in the root zone resulted in high yields of forage even though the rainfall was very low. The data suggest that very high yields of forage would be produced during a full season having normal rainfall and sufficient nitrogen.

Pasture sods are usually not damaged by anhydrous ammonia applicator knives, provided the grass is short. Where the grass is tall some of it may be pulled out of the ground. Where soils are so dry and hard that the knives shatter the soil instead of cutting through it, the grass on the shattered soil may die if rain does not follow in a short time. For application to sod crops a knife with a wide point, as described below, is much superior to conventional knives.

Much larger increases in yield of rice were made from anhydrous ammonia applied in the soil just before planting, at mudding-up for planting, and about four weeks after planting, than when applied in irrigation water at any time, in experiments conducted in Arkansas and Texas (3, 4, 7). When applied in irrigation water the soil closest to where the water enters the field absorbs more ammonia than that farther away. Anhydrous ammonia was compared with and was much superior to ammonium nitrate in the Arkansas experiments. In the Texas experiments, anhydrous ammonia was compared with and was equal or slightly superior to sulphate of ammonia.

Applying anhydrous ammonia five to six weeks ahead of planting rice was less efficient than when applied at planting time or as a top dressing in Texas[1].

AMMONIUM NITRATE IN SOLUTION

Ammonium nitrate in solution is identical with that in bags when both are applied to the soil. The experience with solid ammonium nitrate is applicable for that in solution. However, the use of the solution for top dressing close-growing crops like small grains and pastures presents problems as well as possibilities which are not involved in the use of the solid.

The sodium salt of 2,4-D is soluble in ammonium nitrate in solution, and may be included for weed control. However, it is recommended that the 2,4-D be added to the solution only a short time before its application, until more information is available. When put into a solution of ammonium nitrate, the amine salt of 2,4-D forms a precipitate, the nature of which has not yet been determined.

Most fertilizers, particularly those which contain nitrogen, produce injuries when sprayed on plants. Some plants are badly damaged when

[1] Cheayne, R. L., personal communication.

ammonium nitrate in solution is sprayed on them, while others are injured little. In general, the injury to broad-leafed plants, including many weeds, is more lasting than to narrow-leafed plants, including small grains. To date, the research work has been limited to oats for grain and summer permanent pastures.

Spraying ammonium nitrate in solution on oats burned them badly in some tests and had little effect in others (2). In six tests, the oats recovered in a short time and produced about the same yield as where solid ammonium nitrate was applied. The injury may be largely avoided by applying the solution from swinging hose (Fig. 7), and completely avoided by application through sword-type applicators which slide on top of, or cut into, the soil.

Active spring growth of fall-planted oats begins about the first of March in most of Mississippi. When ammonium nitrate was sprayed on oats, badly infested with weeds, on March 8 and 31, it produced 7 and 5 bushels more oats, respectively, than the solid, but when applied April 12 the solid made 8 bushels more.

The inclusion of 2,4-D with the ammonium nitrate in the solution of ammonium nitrate almost eliminated wild winter peas, vetch and other legumes, and retarded the growth or killed dock and other broad-leafed weeds. In two tests which were badly infested with weeds or legumes, the inclusion of 2,4-D in the solution of ammonium nitrate increased the yield 14 and 15 bushels of oats per acre over solid ammonium nitrate where 40 pounds of nitrogen per acre was applied. In one test where 80 pounds of nitrogen was applied the increase for 2,4-D was 18 bushels of oats per acre. The increase in the yield of oats from the application of 2,4-D was accompanied by a corresponding decrease in the yield of wild winter peas and vetch.

Where oats were not badly infested with weeds and legumes, the use of ammonium nitrate in solution as a spray, with or without the inclusion of 2,4-D, gave practically the same yield as where solid ammonium nitrate was applied.

Spraying ammonium nitrate in solution on permanent summer pastures produced about the same increase in yield as solid ammonium nitrate in two tests in which the rate of application was 66 pounds of nitrogen per acre. However, the spray produced some burning when first applied. The inclusion of 2,4-D for weed control may be practical where the solution is to be sprayed on pastures.

OTHER SOURCES OF NITROGEN IN LIQUID FORM

The response of crops to aqua ammonia is the same as for anhydrous ammonia. It must be applied in the soil and covered simul-

taneously, just as is necessary with anhydrous ammonia, to prevent the loss of the ammonia into the air. Spraying aqua ammonia on the land or on snow probably results in nearly all of the ammonia being lost into the air.

Mixtures of ammonium nitrate or urea and free ammonia will, no doubt, produce about the same increase in yield as anhydrous ammonia and ammonium nitrate. Because of the free ammonia present they must be applied in the soil and covered simultaneously just as is necessary with anhydrous ammonia. If they are not covered properly the free ammonia will be lost into the air.

A mixture of ammonium nitrate and urea in solution should be as effective as ammonium nitrate for crop production. It may be applied directly to the land or sprayed on small grains and pastures as may be done with ammonium nitrate. It is probable that some form of 2, 4-D is soluble in this solution, which would enable its inclusion for weed control.

EQUIPMENT FOR NITROGENOUS FERTILIZERS IN SOLUTION

Anhydrous Ammonia

Anhydrous ammonia has no pressure at 28° F. below zero. At 100° F. it has a pressure of 197 pounds per square inch. At first the high pressures exerted by anhydrous ammonia appear dangerous; they are dangerous, but they are no more dangerous than steam boilers, which have been in common use for a long time.

Many states have rules and regulations concerning equipment for handling anhydrous ammonia. In most cases the regulations should be satisfactory, though improvements no doubt will be made as the information warrants. Those who handle anhydrous ammonia should have a copy of the regulations.

Anhydrous ammonia tanks have a working pressure of 250 pounds per square inch[1]. The test pressure is normally 400 pounds per square inch. The bursting pressure is normally over 1000 pounds per square inch. Tanks are equipped with sufficient pop-off valve area to relieve too much pressure by releasing the gas phase. The release of gas permits more gas to evaporate from the liquid phase; the evaporation of the liquid phase has a cooling effect on the tank and its contents, which reduces the pressure.

All tanks and fittings are made from steel, which is not attacked

[1]High pressure tanks are most common. Horton spheres are large spherical tanks which are refrigerated. They may be of any size but 210,000-gallon capacity is a common size.

by ammonia. Hose is ammonia resistant. Bronze and brass are attacked by ammonia and they should not be used for anhydrous ammonia.

Incomplete filling of tanks is a safety feature. The percentage fill of anhydrous ammonia tanks should not exceed the following:

Temperature of liquid ammonia in tank Degrees F.	Maximum volume filled with liquid Per cent
30	86
40	88
50	
60	90
70	91
80	92
90	93
100	95

Tanks are made to withstand much more than the gas pressure developed under ordinary circumstances. However, if a tank were completely filled with liquid only a little rise in temperature would be sufficient to cause an explosion if the pop-off valve failed to work.

A 30,000-gallon tank holds about 65 tons of anhydrous ammonia, which is sufficient to fertilize about 1,000 acres at a rate of 100 pounds of nitrogen per acre. Ammonia is shipped in 10,000-gallon tank cars, containing 25 to 26 tons (Fig. 4). A 30,000-gallon tank is about the smallest size unit necessary for establishing a business. The effective size of the business may be increased by supplying farmers transport tanks and tractor equipment, or by applying the ammonia to the soil for a fee. Anhydrous ammonia is transported to the farm in 500- to 1000-gallon tanks where it is to be applied directly to the land. Where farm storage is available transport trucks are used.

Nitrogenous fertilizers are produced throughout the year. It is necessary for the manufacturing plants to run continuously. Since most of the nitrogen is applied in the spring it is necessary for it to be stored until used. During periods of scarcity farmers buy solid nitrogenous fertilizers when they become available; during periods of plenty they tend to buy their fertilizer only as needed.

The rate of delivery of anhydrous ammonia to the soil is controlled by the following devices:

1. Needle valve and pressure gauge
2. Pressure regulating valves
3. Flowrator
4. Pump

All of the regulating devices are very accurate provided they have been calibrated and the orifices, delivery lines, and applicator knife open-
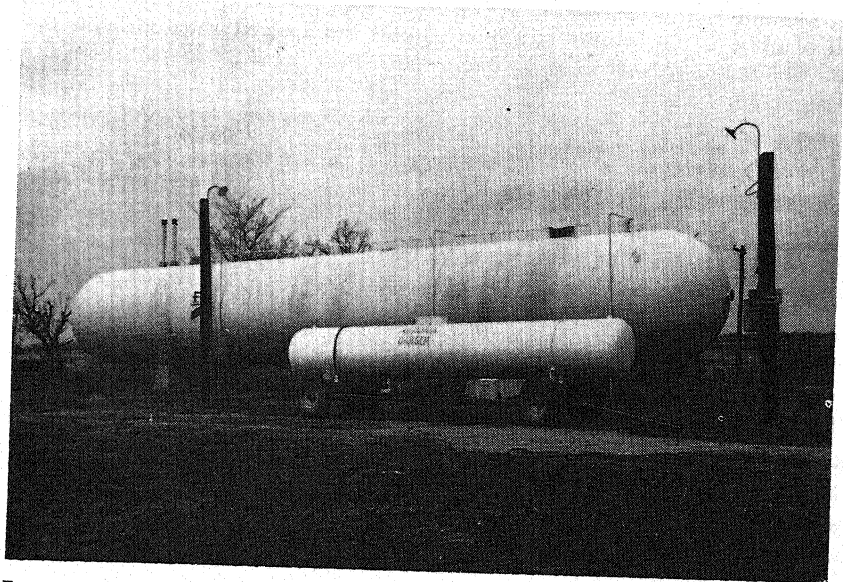
FIG. 4.—Anhydrous ammonia is commonly stored in 30,000-gallon tanks, and transported in 500- to 1000-gallon tanks. (Courtesy Mississippi Agricultural Experiment Station.)

ings are of a uniform size. The manufacturer should provide calibration data for each machine. The devices are listed in order of increasing cost.

The rate of application of anhydrous ammonia per acre by the needle valve and pressure gauge and the pressure regulating valves depends upon tank pressure, orifice size, orifice pressure, and acreage covered per hour.

Even though very accurate metering may be obtained with the needle valve and pressure gauge and pressure regulating valves, the rate of ammonia through them varies with the tank pressure and the valve gauge settings. For example, where it is desired to apply 300 pounds of anhydrous ammonia per hour through four 3/32-inch orifices, an orifice gauge pressure of 37 pounds per square inch is required with a tank pressure of 90 pounds per square inch, while an orifice gauge pressure of 52 pounds is required when the tank pressure goes up to 150 pounds per square inch. If a regulating valve is set so that the orifice gauge pressure is 37 pounds with a tank pressure of 90 pounds per square inch, only 220 pounds of ammonia would be delivered as compared to the desired 300 pounds per hour when the

tank pressure goes up to 150 pounds per square inch, even though the orifice pressure is maintained at 37 pounds per square inch.

There is one automatic regulating valve which partially compensates for changes in tank pressure so that little change in rate of flow of anhydrous ammonia takes place even though the tank pressure varies markedly.

The flowrator is a tapered glass tube, graduated in pounds of nitrogen per hour, the rate of flow is indicated by a rotor which rises as the rate increases. Flow through this instrument is controlled by a needle valve.

The rate of delivery of ammonia by all of the metering devices, except the pump, is a function of time, and a constant speed of the tractor is necessary to maintain a constant rate per acre. The pump is geared to the tractor and should maintain a constant rate of application per acre even though the speed of the tractor varies.

A cooler is used with the pump and flowrator to prevent the formation of vapor in these instruments. The cooler is made from coiled 3/4-inch pipe in a 3 x 12-inch pipe, with the proper fittings. The ammonia comes from the tank through the coil and leaves the pump or flowrator through the larger pipe around the coil. The pressure of the outgoing ammonia is lowered, and the evaporating anhydrous ammonia cools the incoming ammonia, thereby preventing it from bubbling.

Farm tractors are usually equipped with 70- to 110-gallon anhydrous ammonia tanks which are mounted on the tractor. Trailing equipment carries much larger tanks. A 110-gallon tank holds about 420 pounds of nitrogen, equivalent to 1 1/4 tons of nitrate of soda.

Anhydrous ammonia is conducted into the soil through hose connected to the back of applicator knives (Fig. 5). Almost any type of knife does a good job in soils which are loose and friable and free of
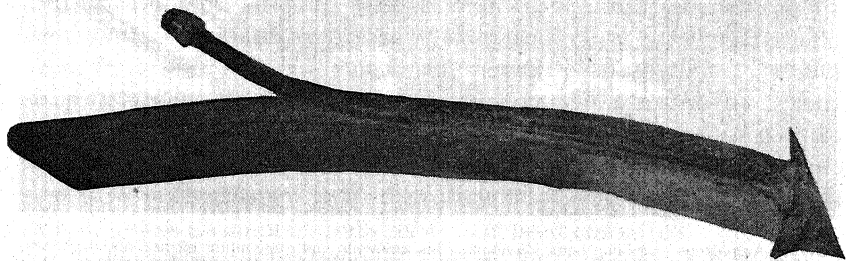
FIG. 5.—A good applicator.(Courtesy Mississippi Agricultural Experiment Station.)

trash. Difficulty in sealing ammonia increases as soils become less friable, more compact and more trashy, and as the rate of application per foot of row increases.

The applicator knife should slope backward and not be sharp above a vertical distance of four inches from the point. The backward slope enables the knife to take the ground and helps it to shed trash. The dull edge also helps in shedding trash. The bottom of the knife should carry an addition to loosen and increase the amount of soil available for absorbing the ammonia. The knife shown in Figure 5 has a 3-inch point of a 10-inch sweep welded on the bottom, which loosens the soil so that a good job of sealing may be done in compact soils and pastures.

A covering device helps seal anhydrous ammonia in the soil. The disk hiller shown in Figure 6 crowds loose soil against the applicator from near the bottom up and prevents the escape of ammonia. Shovels or other covering devices may be used. Even though a covering device is not needed on soils which are loose and friable, it is usually desirable to use one.

In filling tanks the outlet valve on the storage tank should be opened last and closed first. In filling tanks by bleeding, pumps, and

FIG. 6.—Anhydrous ammonia, aqua ammonia, aqua ammonia and ammonium nitrate, and aqua ammonia and urea in solution must be applied in the soil to prevent the loss of the free ammonia. Disk hillers help to seal the ammonia at the point of application. (Courtesy Mississippi Agricultural Experiment Station.)

compressors all connections are made and all valves are opened with the outlet valve on the storage tank being opened last. Then the pump or compressor (if used) is started and the bleeder valve is opened. The escape of a spray from the bleeder valve indicates that the liquid ammonia is up to the filling level, after which the pump or compressor (if used) is stopped, the outlet valve on the storage tank is closed, the bleeder valve is closed, the other valves are closed and the hose disconnected.

The loss in filling tanks by bleeding is about one per cent of the ammonia transferred when the pressure in the tank being filled is only 10 pounds per square inch less than that in the storage tank. If the difference in pressure is 40 pounds per square inch the loss in transferring ammonia is about three per cent. With a starting pressure of 232 pounds per square inch 36 per cent of the ammonia is lost in bleeding to atmospheric pressure.

The gaseous anhydrous ammonia should not be removed from anhydrous ammonia tanks. At 80° F., a 30,000-gallon tank contains 2040 pounds of anhydrous ammonia as vapor, a 1,000-gallon tank contains 68 pounds, and a 100-gallon tank contains 6.8 pounds. At $150 per ton, the ammonia lost in bleeding these tanks after the liquid has been removed is worth $153.00, $5.10 and $0.51, respectively.

Ammonia reacts with the inside of steel tanks in such a way that a protective coating is formed. This layer is lost on exposure to the air and rusting proceeds. Preventing rust is another reason for not releasing the ammonia vapor from tanks.

Anhydrous ammonia is a safe product to handle provided it is handled with care. The following safety precautions should be followed:

1. Obtain a copy of "Rules and Regulations" concerning the storage and handling of anhydrous ammonia from your (or other) state agency which regulates its handling.

2. Buy tanks, equipment and accessories which are made according to underwriters codes.

3. Obtain instructions on transferring ammonia from tank to tank.

4. Maintain rubber gloves, goggles, five gallons of water and a first aid kit on all transport equipment.

5. Apply water immediately to any part of the body on which ammonia comes in contact.

6. Do not put fuel gasses in tanks in which ammonia has been stored, unless a competent authority has been consulted.

7. Recognize that ammonia can produce injury and handle it accordingly at all times.

AMMONIUM NITRATE, UREA AND AMMONIUM NITRATE AND AQUA AMMONIA ALONE AND WITH AMMONIUM NITRATE OR UREA

A machine for applying ammonium nitrate or ammonium nitrate and urea is shown in Figure 7. The essential parts of the machine are: a 55-gallon oil drum, a pump, a manifold and orifices for dividing the solution to the individual rows, and hose for conducting the solutions to the ground.

A variable volume control pump is preferred, even though a by-pass pump may be used to maintain a constant pressure on the orifices. A surge chamber is necessary with piston pumps. The pump should be acid resistant, and the manifold and orifices should be made of aluminum for solutions containing ammonium nitrate.
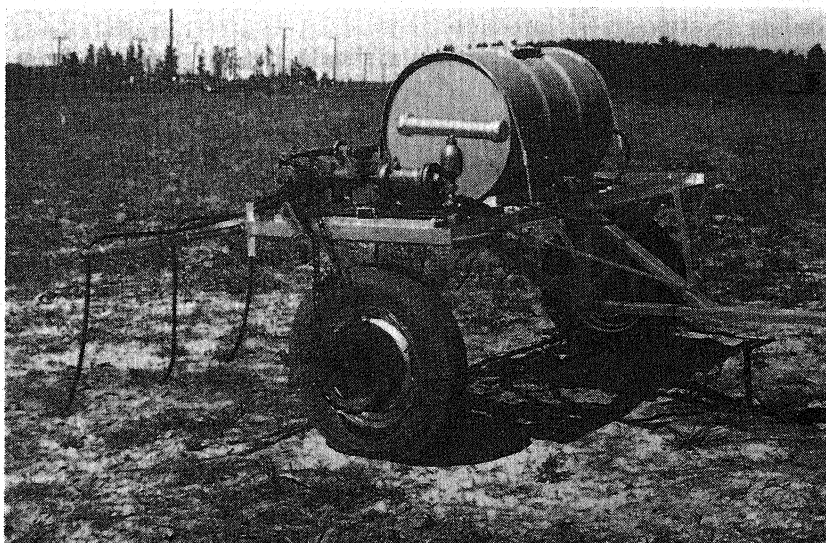
Fig. 7.—Ammonium nitrate or urea and ammonium nitrate in solution may be applied on the surface of the soil. (Courtesy Mississippi Agricultural Experiment Station.)

Spray equipment may be used for ammonium nitrate or ammonium nitrate and urea. These solutions may be applied through sword-type applicators which run shallow or on top of the ground where it is undesirable for them to get on broadcast crops. Applicators similar to those used for anhydrous ammonia may be used for deep application. The hose may also be attached behind plows on cultivators.

Solutions which contain aqua ammonia must be applied in the soil and covered simultaneously to prevent the loss of ammonia, and these solutions are applied through applicators of the type used for

anhydrous ammonia. Acid resistant equipment is not necessary for aqua ammonia alone or mixed with urea. Bronze and brass are not suitable for any of these solutions.

Most of the nitrogenous fertilizers in solution are shipped in tank cars which contain 8,000 to 10,000 gallons.

Ammonium nitrate corroded through an untreated molasses can in less than a month, and in $1\frac{1}{2}$ years when treated with motor oil. Where cans were treated with grease, paraffin, or asphalt paint, they showed no corrosion after more than 1 1/2 years. The cans were not exposed to extreme temperature variations that might have changed the effectiveness of the treatments.

Of the materials available for treating tanks which are to be used for storing ammonium nitrate, the author prefers asphalt paint. It is cheap and easy to apply. It is suggested that the tank be closed, as soon as the asphalt paint will not flow, to reduce the evaporation of the lighter constituents which retard the cracking of the asphalt. No doubt, an annual treatment with a light oil would prolong the life of the paint.

SUMMARY AND CONCLUSIONS

The cheapest nitrogenous fertilizers are in liquid form. Liquids can be handled easier and applied more uniformly than solids.

Anhydrous ammonia is the first nitrogen product made in synthetic nitrogen plants. In addition to the usual solid nitrogenous fertilizers, the liquid forms in which the products of these plants may be used for fertilizer are:

Anhydrous ammonia	82% nitrogen
Aqua ammonia	20-25% nitrogen
Ammonium nitrate and aqua ammonia	36-45% nitrogen
Urea and aqua ammonia	36-45% nitrogen
Ammonium nitrate solution	about 20% nitrogen
Urea-ammonium nitrate solution	about 32% nitrogen

These sources of nitrogen are listed in the order of increasing cost. The characteristics of these materials are:

1. Anhydrous ammonia exerts a high pressure; aqua ammonia, ammonium nitrate and aqua ammonia, and urea and aqua ammonia exert no or low pressures, depending on the percentage of free ammonia and the temperature. Ammonium nitrate and urea-ammonium nitrate in solution exert no pressure.
2. Anhydrous ammonia, aqua ammonia, and urea and aqua ammonia are not corrosive to iron or steel; the others are corrosive, and steel containers should be made thicker and be treated with asphalt paint or other acid resistant material to reduce corrosion.
3. Anhydrous ammonia, aqua ammonia, ammonium nitrate and aqua ammonia and urea-ammonia liquor contain free ammonia,

and they must be applied in the soil and covered to prevent the loss of ammonia; ammonium nitrate and urea-ammonium nitrate in solution may be applied on the surface of the soil without covering, or they may be sprayed on some plants with or without the inclusion of 2,4-D for weed control.

RESPONSE OF CROPS

Experimental work has been done with anhydrous ammonia, the data from which are applicable for aqua ammonia. Experimental work has also been carried out with ammonium nitrate in solution for spraying on small grains and pastures. The data for anhydrous ammonia, except where leaching is a factor, should be applicable for free ammonia and urea or ammonium nitrate in solution. The data on ammonium nitrate in solution should be applicable for urea-ammonium nitrate in solution.

The ammonium form of nitrogen does not leach; only nitrate nitrogen leaches. In the spring ammonia is converted into nitrates in about six weeks in fertile soils. In acid soils and in cold weather more time is required for nitrification.

ANHYDROUS AMMONIA

1. When applied before planting anhydrous ammonia has produced slightly higher yields of both corn and cotton than ammonium nitrate. As a side dressing both have produced the same yields of corn, but ammonium nitrate has produced slightly higher yields of cotton when both were applied in the root zone.
2. Where long dry periods follow application, anhydrous ammonia applied in the root zone has been much superior to ammonium nitrate applied on the surface for corn, cotton and pasture crops.
3. Anhydrous ammonia and ammonium nitrate have been equally efficient for sugar cane, sorghum, sweet potatoes, cabbage, tomatoes and beans.
4. Corn, cotton and many other crops prefer ammonia to nitrate nitrogen while young. Cotton and many vegetable crops prefer nitrate nitrogen during the fruiting period. Where anhydrous ammonia is used for short-season vegetable crops application of all of the nitrogen at or near planting time is recommended, rather than split applications where part of the nitrogen is applied late in the growing season.
5. Because nitrogen applied as anhydrous ammonia does not leach for four to six weeks after application, one application at or near planting time should be equal to a preplanting and a side dressing application for most row crops.
6. In central and north Mississippi anhydrous ammonia applied the last of October to fall-planted oats for grain goes through the winter largely unchanged on strongly acid (below pH 5.0) soils, but much of it changes into nitrate nitrogen and leaches out before spring in soils above pH 5.5.

7. Because of the requirement for nitrate nitrogen by fall-planted small grains in the spring, anhydrous ammonia should be applied as soon as spring growth starts on soils of pH 5.5 or higher, and at least one month earlier on more acid soils.
8. Anhydrous ammonia has been equal to ammonium nitrate for small grains for fall and winter grazing.
9. Nitrogen moves mostly down in soils. Most other fertilizers move little. Anhydrous ammonia, and other fertilizers, should be placed so that young plants can grow roots to it in a short time. Side dressing applied in the middles to slow-growing row crops has the effect of a very late application.
10. A 24-inch spacing of anhydrous ammonia applicators is satisfactory for small grains and other close-growing crops.
11. Anhydrous ammonia, aqua ammonia, and solutions of aqua ammonia and ammonium nitrate or urea should not be applied in contact with superphosphate because free ammonia reduces the availability of the phosphorus.
12. When applied to the soil the behavior of aqua ammonia is the same as that of anhydrous ammonia, and crop response is identical.

AMMONIUM NITRATE IN SOLUTION

1. Ammonium nitrate in solution is equal to solid ammonium nitrate when both are applied in the same position in the soil.
2. Ammonium nitrate applied as a spray or other means of application to oats in the early spring has been equal to solid ammonium nitrate.
3. The sodium salt of 2,4-D may be included in the solution of ammonium nitrate to control weeds in small grains.

OTHER SOURCES OF NITROGEN IN SOLUTION

The response of crops to a solution of aqua ammonia and ammonium nitrate or urea should be intermediate between that for anhydrous ammonia and ammonium nitrate.

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(3)

The Use of Cyanamid as the Source of Nitrogen

The use of cyanamid as a source of nitrogen requires special consideration because crop response to it has not been consistent. Excellent results from the use of cyanamid have been obtained in some cases, and in other cases unsatisfactory results have been obtained. Aside from its effect upon the yield of crops, normally it is one of the cheapest sources of nitrogen available. The sources which supply most of the nitrogen supply it in the nitrate and ammonia forms, or as urea which is quickly converted into ammonia, while cyanamid has its nitrogen in an entirely different form. The form in which cyanamid nitrogen exists, combined with established methods of application of fertilizer, may be responsible for the variable results obtained from its use.

Cyanamid was the first synthetic source of nitrogen. It was introduced in America in 1909. It is made by passing nitrogen over calcium carbide. Calcium carbide is made by heating calcium oxide and coke in the absence of air. As pointed out in Chapter 12. the cost of building, maintaining, and operating a cyanamid plant for the production of nitrogenous fertilizer is high, and it is doubtful if new plants will be built strictly for making fertilizer.

Cyanamid contains 61 to 64% pure cyanamid, 15% hydrated lime, a little lime, 11% carbon, and a small quantity of other elements (1).[1] Pulverized cyanamid has 5% oil added to prevent dustiness. The composition of cyanamid is presented in Table 1. The nitrogen in cyanamid is in the form of calcium cyanamid. When cyanamid is applied to acid soils, it reacts with the acid clay to form acid cyanamid and calcium clay[2]. The acid cyanamid takes up water to form urea. The urea takes up more water and ammonium carbonate is formed. The ammonia goes on the clay particles forming ammonia clay, water, and

[1]Numbers in parenthesis refer to the source of information, page 83.
[2]The action of cyanamid in the soil is essentially the same as that given by Crowther and Richardson (3), and others, except the role of the clay is suggested.

carbon dioxide. The ammonia is used directly by plants, or it is converted into nitrate nitrogen. After nitrogen is converted into the nitrate form, either it is used by plants or it leaches out of the soil in the drainage water.

Cyanamid increases the calcium content of the soil more than any other source of nitrogen. It contains 4.65 pounds of pure lime ($CaCO_3$) for each pound of nitrogen. According to the official method for determining the effect of cyanamid on the lime content of the soil, the use of cyanamid containing one pound of nitrogen should increase the lime content of the soil 2.85 pounds. According to the calculation of Andrews and Cowart (2), it should increase the lime content of the

Table 1.—THE COMPOSITION OF CYANAMID.

	Pulverized "Aero" Cyanamid	Granular "Aero" Cyanamid
	Per cent	Per cent
Calcium cyanamid.....................	63.57	60.71
Calcium hydroxide.....................	15.07	14.15
Calcium carbonate.....................	0.75	4.90
Calcium sulphide.....................	0.81	0.85
Graphitic carbon.....................	11.47	11.10
Iron and aluminum hydroxide...........	1.35	1.27
Silicia.............................	1.31	1.40
Magnesium oxide.....................	0.01	0.01
Trace elements.....................	0.50	0.50
Oil (added to prevent dustiness).........	5.16	.....
Free moisture at 105°C.................	.....	0.36
Combined moisture....................	.....	4.75
	100.00	100.00

soil 1.60 to 1.75 pounds per pound of nitrogen used for cotton production.

In general, good results have been obtained with cyanamid when used in pot work and other places where it has been thoroughly mixed with the soil. The results obtained with cyanamid in the Mississippi Delta (page 15) are illustrative of the results obtained from its use. Where no deficiency of phosphorus or potash existed in the soil, cyanamid made a favorable showing in comparison to other sources of nitrogen. Where the soils were deficient in phosphorus and potash, cyanamid was somewhat inferior to the other sources of nitrogen, and nitrate of soda was much superior.

The practice of drilling together fertilizers containing nitrogen, phosphate, and potash without mixing with the soil appears not to be

the best practice where cyanamid is the sole source of nitrogen. The available data on placement of phosphorus show that it should not be distributed over a band as much as 8 inches wide (see page 379). Cyanamid apparently should not be applied as phosphate and potash are applied on the lighter soils particularly, and the cyanamid itself should be mixed with sufficient soil to prevent an alkaline reaction from developing.

Alternate wetting and drying of granular cyanamid (7) on the surface of the soil causes the calcium hydroxide to come to the surface of the granule, where it is concentrated into an impervious layer, which prevents water from leaching the cyanamid out of the granule into the soil. Similar results may be obtained when cyanamid is applied in the soil and a dry season follows. It, therefore, appears that cyanamid applied to soils low in moisture may be slowly available, and that better results may be obtained when applied to moist soils.

In the hill sections of the cotton belt poor results are often obtained with cyanamid, as is shown by unpublished data from Mississippi (Table 2). In these tests cyanamid produced lower yields than the

Table 2.—The Response of Cotton to Sources of Nitrogen on Upland Soils.

Source of nitrogen	Yield of seed cotton		Yield of corn
	Test No. 1	Test No. 2	
	Pounds per acre		Bus. per acre
No nitrogen	173	543	11
Nitrate of soda	620	1,038	27
Sulphate of ammonia*	646	1,193	26
Uramon*	659	1,113	29
Calcium nitrate	626	1,188	..
Cyanamid	426	948	23

*Dolomite added.

other sources of nitrogen. The leaves of the cotton receiving cyanamid appeared to have been scorched, and had an unthrifty appearance. The fertilizers used in the above tests were drilled, which is the common method of applying fertilizer to cotton. The injury from cyanamid can be reduced by thoroughly mixing it with the soil. Since phosphate should not be mixed with the soil, it appears that cyanamid may be more adapted on soils requiring only nitrogen than on soils requiring phosphorus in addition to nitrogen.

The uncertainty of cyanamid as a source of nitrogen is illustrated

by data in **Table 3 from Alabama** (9). Cyanamid made about as much cotton as nitrate of soda on both the unlimed and limed Norfolk soil, but produced about 200 pounds less seed cotton on the Cecil soil. The data show that cyanamid is a good source of nitrogen on some soils and a poor source on others.

Where crops are injured by cyanamid, the injury is attributed to either the cyanamid itself or to dicyandiamid formed from two units[1]

Table 3.—THE RESPONSE OF COTTON TO SOURCES OF NITROGEN ON THREE SOILS IN ALABAMA.

| Plot No. | Source of nitrogen | Yield of seed cotton—pounds per acre | | Cecil soil (6-year average) |
| | | Norfolk soil (4-year average) | | |
		Unlimed	Limed	
1	Nitrate of soda................	1,069	1,188	1,270
2	Nitrate of soda 3/5, sulphate of ammonia 2/5................	1,134	1,214	1,276
3	Sulphate of ammonia...........	1,004	1,252	1,245
4	Leunasalpeter.................	1,022	1,103	1,336
5	Nitrate of soda................	1,054	1,088	1,331
6	None.........................	409	493	553
7	Cyanamid.....................	1,060	1,078	960
8	Sulphate of ammonia (basic slag)..	1,100	1,154	1,006
9	Nitrate of soda................	1,089	1,110	1,149
10	Ammo-phos A.................	867	1,152	970
11	Urea.........................	1,081	1,250	1,140
12	Nitrate of soda................	999	1,035	1,217
13	Nitrate of soda................	1,214	1,187	.....
14	Calcium nitrate...............	1,190	1,274	.....
15	Cottonseed meal..............	1,047	1,097	.....
16	Nitrate of soda................	1,173	1,191	.....
Average nitrate of soda................		1,100	1,133	1,242

of acid cyanamid. That injuries to young seedlings are sometimes obtained when cyanamid is improperly applied is recognized by the Cyanamid Company (1), which recommends waiting three days before planting for each 100 pounds of cyanamid per acre applied broadcast, and 6 days for each 100 pounds of cyanamid applied in the row.

Fertilizers are generally applied in the drill or row for cotton and most other crops in the Southeast. Cyanamid is very high in lime, as was pointed out above. Where cyanamid is applied in a band, it comes in contact with a small amount of soil, and in the case of sandy soils, the clay is unable to take up all of the lime (calcium) set free as the

[1]Molecules.

cyanamid nitrogen is transformed to other forms of nitrogen. Under these conditions, the small volume of soil in contact with the cyanamid may become strongly alkaline. It has also been shown that nitrogen in cyanamid is changed to urea slowly in sandy soils. The rate of transformation of the nitrogen in cyanamid to urea is higher in soils high in organic matter. It has been suggested that not more than enough cyanamid should be used to supply all of the lime the clay in the soil it comes in contact with can take up. Many sandy loam soils will not take up more than 1,000 pounds of lime per acre when it is mixed with the plow layer. It, therefore, appears that only a very small amount of cyanamid can be used satisfactorily in the drill on sandy soils.

As was pointed out above, when the clay is able to take up the lime when cyanamid is being decomposed, the nitrogen is converted into urea rapidly. However, when the clay is unable to take up all of the lime released, the fertilizer zone becomes alkaline, and acid cyanamid may be changed into dicyandiamid (3). Dicyandiamid is essentially two molecules of acid cyanamid combined.

In concentrated solution both cyanamid and dicyandiamid are poisonous, and dicyandiamid is more poisonous (to nitrifying bacteria at least) than cyanamid (6). It is possible that the harmful effects of cyanamid are due directly to the cyanamid in soils in which it decomposes slowly as well as to dicyandiamid. The rate of production of the poisonous dicyandiamid increases with increase in alkalinity (3) to pH 9.6, after which its rate of production falls off rapidly, and at pH 12.0 none of the poison is formed, and the nitrogen is converted almost completely into urea.

When cyanamid and the poison (dicyandiamid) are properly mixed with heavy soil, and given sufficient time to become available (5), they are not injurious to plants, and even dicyandiamid becomes a good source of nitrogen. In a greenhouse experiment where all of the nitrogen was applied at the beginning of the test, the poison (dicyandiamid) did not increase the yield of corn significantly on the sandy soil, and not until the third and fourth crops after the nitrogen had been applied to the loam soil (Table 4).

If dicyandiamid were not poisonous and only unavailable to plants for a limited time, its formation would still be undesirable, in the Southeast particularly, because much of it would become available at a time of the year when no plants are growing. Fertilizers are used largely in humid climates, and in humid climates nitrogen which becomes available when crops are not growing on the land is largely lost, particularly where the temperatures are high.

Table 4.—THE UTILIZATION OF CYANAMID AND DICYANDIAMID BY CORN IN THE GREENHOUSE.

Source of nitrogen	Loam soil					Sand soil				
	Crop number									
	1	*2*	*3*	*4*	*Total*	*1*	*2*	*3*	*4*	*Total*
	Yield of corn[1]									
No nitrogen......	5.0	4.3	5.2	8.2	22.7	6.9	4.9	4.9	10.7	27.4
Nitrate of soda....	7.4	7.8	7.0	9.9	32.1	8.1	8.1	6.9	12.0	35.1
Cyanamid........	8.0	7.0	6.4	9.6	31.0	7.8	5.8	6.6	12.1	32.3
½ cyanamid, ½ dicyandiamid...	6.9	5.3	10.1	9.4	31.7	7.6	6.1	6.0	11.8	31.5
Dicyandiamid....	5.1	4.0	12.6	10.0	31.7	6.3	5.0	5.6	11.3	28.2

[1] Grams per pot.

The storage of cyanamid on the farm brings on problems which are not present with other fertilizers (8). When cyanamid is stored in good bags in a dry place, no change takes place, and it retains its original value. However, when the bags are open, the calcium hydroxide in the cyanamid takes up carbon dioxide to form calcium carbonate. Where water is taken out of the air, cyanamid may decompose to give dicyandiamid and urea.

Mixing pulverized cyanamid and superphosphate causes water-soluble phosphorus to be changed into water-insoluble dicalcium and tricalcium phosphate and the cyanamid nitrogen to be changed to dicyandiamid (8). The data in Table 5 show that mixing superphosphate and pulverized cyanamid together caused a very marked rise in temperature. The addition of cyanamid in quantities greater

Table 5.—THE EFFECT OF PULVERIZED CYANAMID ON THE WATER-SOLUBLE PHOSPHORUS IN SUPERPHOSPHATE.

Per cent cyanamid	*Per cent of total nitrogen as dicyandiamid*	*Per cent of phosphorus water soluble*	*Temperature rise, degrees centigrade*	*Per cent of water*
1	0	82	5	13
3	1	86	5	13
5	7	87	15	12
7	11	77	28	12
10	26	55	44	12
20	51	trace	74	7
35	35	none	86	5
50	18	none	92	3

than 5% of the mixture caused marked reductions in the water-soluble phosphate, and when 20% of the mixture was cyanamid, all of the water-soluble phosphate was made insoluble in water. Fifty-one per cent of the nitrogen was converted into the slowly available dicyandiamid when the mixture contained 20% cyanamid. When dry granular cyanamid and dry superphosphate are mixed, no change takes place, but it is possible that the changes take place in the soil when the mixture gets wet.

The heat produced when pulverized cyanamid and superphosphate are mixed has a drying effect, as shown by the reduction in moisture content with each increase in percentage of cyanamid. When monocalcium phosphate is changed to dicalcium phosphate, more water of crystalization is formed, which aids in drying the mixture.

Granular cyanamid and superphosphate mixtures can be stored in air-tight bags in a dry place. When the mixture is permitted to take up moisture from the air, reactions take place which may reduce its value for fertilizer. Apparently cyanamid mixtures should be applied as soon as convenient after mixing.

Granular cyanamid can be mixed with superphosphate without appreciable reversion of the phosphorus to less available forms before it is applied to the soil. Where a mixture of these materials is applied to the soil in the drill, the reactions given for pulverized cyanamid may take place in the soil; where a mixture of this kind is applied in a broader band than fertilizers are normally applied, the phosphorus becomes less efficient.

Pulverized cyanamid is used in mixed fertilizer (about 60 pounds per ton) to neutralize the free acid in superphosphate. In making superphosphate, more sulphuric acid is sometimes used than is necessary to shorten the curing time. The excess of sulphuric acid reacts with monocalcium phosphate to form calcium sulphate and free phosphoric acid. The free phosphoric acid gives superphosphate poor handling properties and destroys the bags in which it is shipped. The free lime in the cyanamid reacts with the free phosphoric acid to give monocalcium phosphate. The change may proceed until dicalcium or tricalcium phosphates are formed. Dicalcium phosphate takes up more water of crystalization than monocalcium phosphate, heat is given off, and the mixture becomes drier.

SUMMARY

Cyanamid is one of the cheapest sources of nitrogen; however, its use deserves special consideration. Excellent results have been ob-

tained from the use of cyanamid in some cases, and unsatisfactory results have been obtained in other cases. It contains more lime per pound of nitrogen than any other source of nitrogen. The experimental results obtained with cyanamid indicate:

1. As fertilizers are most generally applied, cyanamid is a good source of nitrogen on some soils.
2. Cyanamid is usually more satisfactory when used on heavy soils than when used on light soils.
3. Cyanamid should be mixed with the soil; superphosphate should not be mixed with the soil; cyanamid is more widely used where nitrogen only is applied to crops.
4. The cost of nitrogen in cyanamid is usually lower than that in other solid sources of nitrogen; consequently, it would be well for a farmer to try it out and see if cyanamid is a good source of nitrogen on a particular soil.

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(4)

The Effect of Fertilizers on the Available Lime, Phosphate and Potash in Soils

Acids leach lime and potash out of the soil.

The data reviewed in Chapter 1 show that in short-time tests there is usually not a great difference in the response of crops to sources of nitrogen unless the soil is deficient in potash or phosphorus. Where phosphorus and potash deficiencies exist in soils, nitrate of soda often produces larger increases in yield than other sources of nitrogen, even though a sufficiency of superphosphate and muriate of potash is applied in the fertilizer. It was also pointed out that the difference between sulphate of ammonia and nitrate of soda was not overcome by the use of dolomite with sulphate of ammonia.

In long-time tests, on unlimed soil, sources of nitrogen like nitrate of soda, calcium nitrate, and cyanamid, produce greater increases in yield than sources like sulphate of ammonia, urea, leunasalpeter and ammo-phos A.

In this chapter the changes in the available nutrients produced by the application of the different sources of nitrogen to the soil will be studied. The experimental data on the effect of fertilizers on the soil have been calculated to pounds of phosphate, potash, and lime per 2,000,000 pounds of soil. The weight of an acre of soil to a depth of 6 2/3 inches is approximately 2,000,000 pounds. The reason for presenting the data in this form is that farmers buy phosphorus containing fertilizers on the basis of their phosphate (phosphoric acid) content, potash containing fertilizers on the basis of their potash content, and calcium as lime. Most of the experimental data have been reported by the investigators as parts per million or as milliequivalents per 100 or 1,000 grams of soil. Data reported on this basis can be interpreted easily by chemists. However, this method of reporting data is not understood by all who are interested in soils and fertilizers.

It is recognized that fertilizers may affect soil to a depth greater

than 6 2/3 inches and more than 2,000,000 pounds of soil, but the data have usually been collected from a depth representing approximately 2,000,000 pounds of soil, and the relative effects of the fertilizers are brought out on this basis. The available phosphorus and potash were usually extracted from the soil with a 1.26% solution of nitric acid, or with a neutral salt solution.

The oldest nitrogen sources test in the United States is being conducted by the Pennsylvania Agricultural Experiment Station (3).[1] The test was started in 1882. The effect of sources of nitrogen on the yield of crops was reported previously (page 1); the effect of sources of nitrogen upon pH, and available phosphoric acid, potash and lime are reported in Table 1.

Table 1.—THE EFFECT OF SOURCES OF NITROGEN ON THE AVAILABLE PHOSPHATE, POTASH, AND LIME IN THE SOIL.

Source of nitrogen[1]	pH	Pounds of available nutrients per acre		
		Phosphate	Potash	Lime
Dried blood...........	5.05	24	374	1,950
Nitrate of soda........	5.35	17	386	2,625
Sulphate of ammonia...	4.45	29	296	375
No nitrogen...........	5.27	26	362	2,750
No fertilizer..........	5.33	9	293	2,650

[1]All plots received 48 pounds of nitrogen, 48 pounds of phosphate, and 100 pounds of potash per acre per year.

The application of potash with superphosphate increased the potash content of the soil from 294 to 362 pounds per acre. An increase in potash content of the soil took place where nitrate of soda and dried blood were used, even though much more potash was removed in the larger yields of crops produced on these plots. The yields obtained where sulphate of ammonia, superphosphate and no fertilizer were applied were very low.

The use of sulphate of ammonia reduced the pH from 5.27 to 4.45, and the lime in the soil from 2,750 to 375 pounds per acre. Dried blood reduced the lime to 1,950 pounds per acre. Sulphate of ammonia, as compared to other sources of nitrogen, reduced the available potash considerably, even though little potash was removed in the low yields of crops produced during the last years of the test. The pH and lime content of the soil were maintained but not increased by nitrate of soda. The available phosphorus was changed very little by the different sources of nitrogen.

[1] Numbers in parenthesis refer to the source of information, page 104.

One of the most wisely planned, long-time nitrogen sources tests was conducted at the Rhode Island Agricultural Experiment Station (4) (1893-1926). After the test had been going for 22 years, lime was added periodically to maintain the pH above 6.0 on one nitrate of soda plot and on one sulphate of ammonia plot. Lime was also added to one sulphate of ammonia plot to maintain the pH equal to that where nitrate of soda was applied without lime. The data are reported in Table 2.

Table 2.—THE EFFECT OF SOURCES OF NITROGEN AND LIME ON THE AVAILABLE LIME, PHOSPHATE, AND POTASH, AND ON THE SOLUBLE ALUMINUM IN THE SOIL.

Sources of nitrogen[1]	Lbs. Lime added	pH 1927	Pounds of available nutrients per acre					
			Phos-phate	Potash	Lime	Acetic acid soluble alumina		
						1924	1925	1926
Sulphate of ammonia..	7,140	5.2	740	362	1,790	74	...	..
Sulphate of ammonia..	25,600	6.3	629	282	3,850	34	190	66
Nitrate of soda.......	0	5.2	680	366	1,850	42	...	..
Nitrate of soda.......	16,700	6.3	579	275	4,115	16	80	34

[1]49 pounds nitrogen, 112 pounds phosphoric acid, and 105 pounds potash was applied per acre per year.

In order to maintain the reaction of the nitrate of soda plot near pH 6.0, it was necessary to apply 16,700 pounds of lime during the 1914 to 1927 period. In order to maintain the reaction where sulphate of ammonia was applied near pH 6.0, 25,600 pounds of lime was applied during the same period. The sulphate of ammonia plot, which was maintained near pH 5.2, received 7,140 pounds of lime.

It required 109 pounds more lime per 100 pounds of sulphate of ammonia to maintain the reaction of the soil at pH 6.3 than where nitrate of soda was used; it required 88 pounds of lime per 100 pounds of sulphate of ammonia to maintain the pH equal to that on the un-limed nitrate of soda plots. Lime was not added to any plot for 22 years after the test was started. During this period sulphate of ammonia did not leach as much lime out of the soil as it would have if the lime content of the soil had been maintained. Consequently, more than 88 or 109 pounds of pure lime per 100 pounds of sulphate of ammonia would have been required by the sulphate of ammonia plots to maintain the lime content of the soil throughout the experiment equal to that where nitrate of soda was used (5).

During the latter part of the period, the sulphate of ammonia with

little lime and the unlimed nitrate of soda plot produced low crop yields. The application of lime increased the yield and reduced the available phosphate and potash, which indicates a greater removal of these elements in the increased crop yields. By the use of lime, the available phosphorus and potash in the sulphate of ammonia plots was maintained equal to that where nitrate of soda was used.

Soluble aluminum combines with phosphorus and makes it unavailable to plants. The application of lime reduced the soluble aluminum to approximately one-half of that without lime. **At the same pH and almost equal lime contents, the soluble aluminum where nitrate of soda was applied was only about one-half of that found where sulphate of ammonia and lime were used.** The decrease in soluble aluminum where lime was used was probably due to the formation of more insoluble aluminum compounds; the decrease in soluble aluminum where nitrate of soda was used may have been due to the formation of a more soluble aluminum compound which leached out of the soil.

The effect of sources of nitrogen on the loss of potash (Connecticut) from soil (6) in tanks is shown by data where 996 pounds of nitrogen and 1006 pounds of potash per acre was added over a 5-year period (Table 3). Nitrate of soda reduced the loss of potash by leaching

Table 3.—THE EFFECT OF SOURCES OF NITROGEN ON THE LOSS OF POTASH FROM SOIL IN TANKS

Source of nitrogen	Pounds of potash lost per acre		
	Leached	In crop	Total
No nitrogen................	486	167	653
Nitrate of soda..............	442	431	873
Sulphate of ammonia........	879	262	1,141
Urea......................	479	385	864
Cottonseed meal...........	638	372	1,010

slightly; urea had no effect, and cottonseed meal increased the loss of potash by leaching by about one-third. The application of sulphate of ammonia caused 437 pounds more potash to leach out of the soil than where nitrate of soda was applied. On the basis of these data, 360 pounds more 50% muriate of potash was leached out of the soil per ton of sulphate of ammonia than where an equal quantity of nitrogen was applied as nitrate of soda. Cottonseed meal increased the leaching of potash considerably. The increased loss of potash produced by the use of cottonseed meal may have been due to its sulphur content.

The effect of sources of nitrogen on the magnesium content of the soil (6) is shown by data from Connecticut, where 996 pounds of nitrogen and 543 pounds of lime equivalent in magnesium was applied (Table 4). More than 3 times as much magnesium was leached out of

Table 4.—THE EFFECT OF SOURCES OF NITROGEN ON THE LOSS OF MAGNESIUM FROM SOIL IN TANKS.

Source of nitrogen	Pounds of magnesium lost as lime equivalent per acre		
	Leached	In crop	Total
No nitrogen	270	75	345
Nitrate of soda	229	184	413
Sulphate of ammonia	706	111	817
Urea	355	189	544
Cottonseed meal	347	200	547

the soil with sulphate of ammonia as with nitrate of soda. Where sulphate of ammonia is applied, the magnesium leaches out as magnesium sulphate, which is very soluble. Urea and cottonseed meal increased the loss of magnesium by leaching slightly. Dolomite contains magnesium, and it usually increases the yield of cotton where sulphate of ammonia is used as the source of nitrogen.

The effect of sources of nitrogen on the leaching of lime (6) is shown by the data in Table 5 from Connecticut where 996 pounds of nitrogen

Table 5.—THE EFFECT OF SOURCES OF NITROGEN ON THE LOSS OF LIME FROM SOIL IN TANKS.

Source of nitrogen	Pounds of lime lost per acre		
	Leached	In crop	Total
No nitrogen	914	138	1,052
Nitrate of soda	980	375	1,355
Sulphate of ammonia	3,090	257	3,347
Urea	1,628	428	2,056
Cottonseed meal[1]	1,383	315	1,698

[1]The soil treated with cottonseed meal received only 291 pounds of lime.

and 932 pounds of lime was applied. Nitrate of soda had very little effect on the loss of lime by leaching. Sulphate of ammonia increased the loss of lime by leaching from 914 to 3,090 pounds per acre; urea increased the loss to 1,628 pounds per acre, and cottonseed meal increased the loss to 1,383 pounds of lime per acre.

The effect of source of nitrogen on the loss of nitrogen (Connecticut) from soil (6) in tanks is shown by data where 996 pounds of nitrogen per acre was added over a 5-year period (Table 6). The total amount of nitrogen recovered in the crop and in the drainage water was 1,125 pounds for nitrate of soda, 914 for sulphate of ammonia, 810 pounds for urea, and 709 pounds for cottonseed meal. The smallest recovery of nitrogen was obtained from cottonseed meal, which must be decomposed and the nitrogen converted into ammonia and nitrate, followed by urea, which has to be changed into ammonia and nitrate, followed by sulphate of ammonia, the nitrogen of which has to be converted into nitrate before leaching out of the soil.

Table 6.—THE EFFECT OF SOURCES OF NITROGEN ON THE LOSS OF NITROGEN FROM SOIL IN TANKS

Source of nitrogen	Pounds nitrogen leached		Pounds nitrogen in crops	Total nitrogen in crops and leached
	As nitrate	As ammonia		
No nitrogen...............	210	1	82	293
Nitrate of soda............	753	4	368	1,125
Sulphate of ammonia......	671	3	240	914
Urea.....................	491	1	318	810
Cottonseed meal..........	427	1	281	709

The New Jersey nitrogen sources test contains more sources of nitrogen than any of the other long continued tests (Table 7). It was started in 1908. The data on the analysis of the soil were obtained on soil samples collected in 1926 (3). The unlimed soil without fertilizer treatment had a pH of 4.6, and 55 pounds of available phosphoric acid, 325 pounds of available potash, and 725 pounds of lime. The addition of superphosphate and muriate of potash increased the pH to 4.85, the phosphate to 353 pounds, the potash to 675 pounds, and the lime to 1,975 pounds per acre.

The application of nitrate of soda increased the pH from 4.85 to 5.20, the phosphate from 353 to 486, the potash from 675 to 781 pounds per acre, and had no effect on the lime content of the soil. The use of calcium nitrate decreased the phosphate from 353 to 269 pounds per acre, decreased the potash slightly, and increased the lime content 525 pounds per acre. Cyanamid increased the available phosphorus slightly and the lime content significantly, and decreased the available potash from 675 to 540 pounds per acre.

The greatest change was produced by sulphate of ammonia, which

lowered the pH from 4.85 to 4.25, decreased the lime from 1,975 to 675 pounds per acre, and had no effect on the available potash. Dried blood increased the available phosphate and potash and decreased the lime supply of the soil slightly.

The limed soil without fertilizer treatment had a pH of 6.35 and 579 pounds of phosphate, 364 pounds of potash, and 4,525 pounds of lime.

Table 7.—The Effect of Sources of Nitrogen on the pH, Phosphorus, Potash, and Lime Content of the Soil (New Jersey).

Source of nitrogen[1]	pH	Pounds per acre—available		
		Phosphate	Potash	Lime
Unlimed soil				
Phosphate and potash only.....	4.85	353	675	1,975
No fertilizer.................	4.60	55	325	725
½ nitrate of soda.............	5.25	318	636	1,850
Nitrate of soda..............	5.20	486	781	1,950
Calcium nitrate..............	5.15	269	622	2,500
Sulphate of ammonia..........	4.25	420	670	675
Cyanamid...................	5.35	386	540	2,775
Dried blood.................	4.75	396	757	1,525
Limed soil				
Phosphate and potash only.....	6.45	478	675	5,375
No fertilizer.................	6.35	579	364	4,525
½ nitrate of soda.............	6.35	502	745	5,650
Nitrate of soda..............	6.55	502	757	7,000
Calcium nitrate..............	6.50	562	328	6,450
Sulphate of ammonia..........	6.20	691	742	6,850
Cyanamid...................	6.35	425	453	7,750
Dried blood.................	6.05	100	316	5,175

[1]Fertilizer applied per acre per year:

840 lbs. superphosphate until 1922—afterwards 320 lbs.
320 lbs. muriate of potash until 1922—afterwards 160 lbs.
320 lbs. of nitrate of soda or its equivalent in other sources.

The addition of superphosphate and muriate of potash resulted in less phosphate and more potash and lime in the soil. The available potash and phosphorus were high where nitrate of soda and sulphate of ammonia were used, and low where calcium nitrate and cyanamid were used.

The effect of nitrate of soda and sulphate of ammonia at Rothamsted, England on the loss of lime from the soil (7) is shown by the following data:

| | Lime lost per acre by leaching | | |
	No fertilizer	Nitrate of soda	Sulphate of ammonia
Broadbalk field........	800	565	1,100
Hoos field............	675	595	775

In the Broadbalk field 535 pounds per acre more lime was lost each year where sulphate of ammonia was used than where nitrate of soda was used. The Hoos field soil lost only 180 pounds more lime per acre where sulphate of ammonia was used than where nitrate of soda was used. The use of nitrate of soda reduced the loss of lime by leaching.

A dilute solution of soda is used to remove fluorine from fluor-phosphate formed when a mixture of tricalcium phosphate and calcium hydroxide is used to remove fluorine in water purification (1). On limed soils available phosphorus is converted to relatively unavailable fluorphosphate. If a dilute solution of soda can be used to remove fluorine from fluorphosphate, it appears that soda from nitrate of soda could prevent its formation in the fertilizer zone. The increase in available phosphorus found in the soil as a result of using nitrate of soda is probably due to a reduction in the amounts of slightly available fluorphosphate formed.

The response of cotton to lime where acid-forming sources of nitrogen are used is shown by the data reported in Table 8. The data for the ten-year period show that sulphate of ammonia and ammo-phos, which are acid forming, produced less seed cotton than nitrate of soda (2). The pH of the soil where the different treatments were used varied from 5.6 to 6.1 in most cases. In the spring of 1937 the sulphate of ammonia and the ammo-phos plots were treated with sufficient lime to bring the pH up to 6.8, and on this year these two sources of nitrogen produced 231 and 221 pounds of seed cotton, respectively, more than nitrate of soda. These data suggest that all of the plots may have needed lime for cotton production.

The residual effect of phosphorus on the yield of cotton where different sources of nitrogen were applied is shown by the data reported in Table 9. The source of nitrogen test was conducted for 10 years prior to the time the data reported were collected (2). All plots received sulphate of ammonia and potash on the year the data were collected from which the response to previously applied phosphorus may be obtained. The fertilized plots received 48 pounds of phosphate

Table 8.—Yield of Seed Cotton in Pounds per Acre, and the Reaction and Readily Available Phosphorus of the Soil with Different Sources of Nitrogen.

Plot No.[1]	Source of nitrogen[2]	Yield of seed cotton, per acre		
		10-year average 1927-1936	1936	After liming plots 4 & 12 1937
		Pounds	Pounds	Pounds
1	No fertilizer—check........	837	731	806
2	No nitrogen—check........	912	875	982
3	Nitrate of soda...........	1,394	1,567	2,065
4	Sulfate of ammonia........	1,236	1,338	2,296
5	Nitrate of soda ⅔..........	.....	.....	.....
	Sulfate of ammonia ⅓......	1,334	1,401	1,901
6	Granular cyanamid[3]........	1,290	1,506	1,879
7	Calcium nitrate...........	1,354	1,560	2,004
8	Calcium cyanamid.........	1,271	1,487	2,038
9	Urea....................	1,273	1,381	1,896
10	Nitrate of soda ½.........	.....	.....	.....
	Cottonseed meal ½........	1,343	1,487	1,913
11	Nitrate of soda-potash......	1,396	1,716	2,102
12	16-20-0 ammo-phos........	1,261	1,382	2,286

[1]Four series or replications from 1927 through 1934; two series since 1934.
[2]600 lbs. of 5-8-8 fertilizer.
[3]Leunasalpeter was used on this plot previous to 1934.

Table 9.—The Effect of Previously Applied Sources of Nitrogen on the Available Phosphorus as Measured by Yield of Cotton.

Source of nitrogen in a 5-8-8 mixture— 600 lbs. per acre applied for 10 years (1927-1936)[1]	Yield of seed cotton without phosphate fertilization in 1937— lbs., per acre
No fertilizer—check............................	1,455
No nitrogen—check............................	1,693
Nitrate of soda................................	2,038
Sulfate of ammonia[3]...........................	1,891
Nitrate of soda ⅔—Sulfate of ammonia ⅓......	1,855
Granular cyanamid[2]............................	1,884
Calcium nitrate................................	1,737
Pulverized cyanamid...........................	1,980
Urea..	1,769
Nitrate of soda ½—Cottonseed meal ½........	1,798
Nitrate of soda-potash.........................	1,913
16-20-0 ammo-phos[3]...........................	1,909

[1]Four series of replications of plats from 1927 through 1934; two series since 1934.
[2]Leunasalpeter was used on this plot previous to 1934.
[3]Limed on March 5, 1937.

and 48 pounds of potash annually for the ten-year period prior to the time the test was conducted.

The data show that the previously applied phosphorus without nitrogen increased the yield of seed cotton 238 pounds per acre, to which increases of up to 345 pounds of seed cotton may be added where the different sources of nitrogen were used. The data show that the residual effect of phosphorus where nitrate of soda was used was greater than where any other source of nitrogen was used; however, the difference was small as compared to pulverized cyanamid. If the data were averaged for both cyanamid treatments, the superior residual effect of phosphorus where nitrate of soda was applied may be significantly greater than where any other source of nitrogen was used.

The Alabama Experiment Station has probably collected more data on the effect of more sources of nitrogen on the soil (3) than most of the other experiment stations (Table 10). Nitrate of soda and cyanamid

Table 10.—THE EFFECT OF SOURCES OF NITROGEN ON THE AVAILABLE PHOSPHATE, POTASH, AND LIME IN THE SOIL. (1911-1926.)

Source of nitrogen[1]	pH	Pounds per acre—available		
		Phosphate	Potash	Lime
Nitrate of soda.............	5.60	118	169	1,240
Cyanamid.................	5.85	152	149	2,325
Check....................	5.45	135	143	780
Sulphate of ammonia........	4.55	112	121	360

[1]Fertilizer treatment: 22.5 pounds of nitrogen, 160 pounds of superphosphate, and 100 pounds of kainit per year.

increased the lime content of the soil significantly, with cyanamid having the greater effect. Sulphate of ammonia reduced the available potash, and decreased the lime to only 360 pounds per acre.

The effect of nitrogen sources upon the pH and the potash and lime content of the soil is shown by data collected by the Alabama Experiment Station (9) (1926-1931) (Table 11). The data show that nitrate of soda increased the pH of the soil slightly, maintained its calcium content, and increased the potassium content in two cases out of three. Calcium nitrate had about the same effect on the pH and lime content of the soil as nitrate of soda, but the potash content of the soil decreased slightly where calcium nitrate was used as compared to where nitrate of soda was used.

Cyanamid increased the pH and calcium content of the soil more than nitrate of soda, and decreased the potash content. Urea and

cottonseed meal reduced the pH and lime content of the soil slightly below that where nitrate of soda was used. Cottonseed meal reduced the potash content slightly, and urea reduced it considerably below that where nitrate of soda was applied.

Sulphate of ammonia, leunasalpeter, and ammo-phos A lowered the pH and lime content of the soil to a very low level on the unlimed soils, and lowered them more than was calculated on the limed soil. The limed Norfolk soil received the calculated amount of lime, on the basis of the official method for determining the effect of sources of nitrogen

Table 11.—THE EFFECT OF SOURCES OF NITROGEN ON THE pH, LIME AND POTASH CONTENT OF THE SOIL (ALABAMA).

Source of nitrogen[1]	Unlimed Norfolk			Unlimed Cecil			Limed Norfolk		
	pH	Lime	Potash	pH	Lime	Potash	pH	Lime	Potash
		Lbs. per acre			Lbs. per acre			Lbs. per acre	
Nitrate of soda.........	5.8	1,020	141	6.5	3,100	405	5.8	1,650	113
Nitrate of soda 60% and sulphate of ammonia 40%.........	5.0	670	122	5.6	3,150	339	5.8	1,460	97
Sulphate of ammonia...	4.6	290	57	4.8	2,000	292	5.2	1,170	81
Leunasalpeter.........	4.7	630	104	4.9	3,070	311	5.6	1,250	97
Nitrate of soda.........	5.6	910	141	6.5	3,420	424	6.1	1,680	109
No nitrogen...........	5.3	940	113	5.9	3,310	320	5.8	1,580	138
Cyanamid............	5.9	1,400	38	6.8	4,500	311	6.3	2,170	92
Sulphate of ammonia and basic slag.......	6.1	2,300	47	6.6	5,620	207	6.2	2,380	97
Nitrate of soda.........	5.4	1,090	47	6.3	3,350	367	5.9	1,780	138
Ammo-phos A.........	4.5	320	85	5.1	2,030	480	5.1	1,200	202
Urea................	5.2	910	38	5.6	3,040	311	5.5	1,560	113
Nitrate of soda.........	5.3	970	104	6.1	3,720	320	5.8	1,630	141
Nitrate of soda.........	5.2	1,270	141	...	...	...	5.8	1,750	129
Calcium nitrate.......	5.2	1,320	104	...	...	...	5.8	1,630	109
Cottonseed meal.......	5.2	1,240	104	...	...	...	5.3	1,380	105
Nitrate of soda.........	5.6	1,290	122	...	...	...	5.9	1,550	122

[1]Fertilizer treatment: 45 pounds of nitrogen, 96 pounds of phosphate (195 on ammo-phos A plot) and 100 pounds of muriate of potash per acre per year. The limed soil received lime calculated to maintain a pH of 6.5 on all plots.

on the lime content of the soil, to maintain the pH at 6.5. A pH of 6.5 was not maintained on any plot. Sulphate of ammonia and leunasalpeter decreased the potash content of the soil considerably below that where nitrate of soda was applied.

The unlimed Norfolk, Cecil, and limed Norfolk soils had 85, 480, and 202 pounds of potash per acre, respectively, where ammo-phos A was applied; the potash in the adjacent nitrate of soda plots was 47, 367, and 138 pounds, respectively per acre. Ammo-phos A is strongly acid and nitrate of soda is slightly basic. The difference in the leaching of potash where these two sources of nitrogen were applied is probably due to the low concentration of salts where ammo-phos A was applied.

The data on the Alabama plots were obtained where fertilizers were applied in a band. In this test, the superphosphate, muriate of potash,

and one-half of the nitrogen were applied 10 to 14 days before planting cotton, and the other half of the nitrogen was used as a side dressing, except that ammo-phos A and cyanamid were applied before planting after the second year of the test. Since the fertilizers were applied in the drill, the elements forming the most soluble salts would tend to leach out in the drainage water first. Also a large amount of any salt would tend to deplete the clay of bases not applied in the salt. The salt calcium sulphate in fertilizers may be responsible for potash leaching out of the soil.

Table 12.—THE EFFECT OF SULPHUR IN FERTILIZERS ON THE pH AND AVAILABLE POTASH LEFT IN SOILS.

Source of Nitrogen	Pounds of sulphur in contact with the potash in 6 years	Soil					
		Unlimed Norfolk		Cecil		Limed Norfolk	
		Lbs. potash	pH	Lbs. potash	pH	Lbs. potash	pH
Ammo-phos A[2]............	None	179	4.9	518	5.3	177	5.0
Nitrate of soda[1]..........	259	141	5.8	405	6.5	113	5.8
60% nitrate of soda and 40% sulphate of ammonia[1].	321	122	5.0	339	5.6	97	5.8
Leunasalpeter[1]...........	331	104	4.7	311	4.9	97	5.6
Sulphate of ammonia[1].....	413	57	4.6	292	4.8	81	5.2

[1]These plots received 600 pounds of superphosphate, and all plots received 100 pounds of muriate of potash.
[2]Differences between ammo-phos A and an adjacent nitrate of soda plots were added to the above data for nitrate of soda.

The effect of the sulphur on the loss of potash when fertilizers are applied in the drill is shown by the data (9) in Table 12. The sulphur in the fertilizers was carried by the calcium sulphate in superphosphate and sulphate of ammonia. The fertilizers were applied in the drill for cotton. The sulphur in the nitrogen sources applied as a side dressing was not included in the calculations. The available potash in the three soils after six years of fertilization decreased with each increase in the amount of sulphur in the fertilizer. The available potash left in the soil was two to three times as high on the ammo-phos A plot which received no sulphur as on the sulphate of ammonia plots which received 413 pounds of sulphur in 6 years. The sulphur in the fertilizers probably converted potash into water-soluble potassium sulphate, which leached out of the soil. Small amounts of sulphur are required by plants, but

these data suggest that only the minimum sulphur requirement for plants should be included in fertilizers.

The pH of the soil has been considered to play a major role (3) in the loss of potash from the soil. The pH of the soil receiving ammophos A and sulphate of ammonia was practically the same; the ammophos A plots had about twice as much available potash as the sulphate of ammonia plots. The above data show that the pH of the soil had little if anything to do with the loss of potash. One of the most important factors in the loss of potash from the soil when fertilizers are applied in a band is, apparently, sulphur.

Even though the relation of the amount of sulphur to leaching of potash above appears to be convincing, there are other data (11) which do not show that sulphur has a measurable effect on the loss of potash by leaching under field conditions. The reason for the differences in the results is not known.

The effect of sulphur in superphosphate and sulphate of ammonia on the leaching of potash is shown by (unpublished) data from Mississippi (Table 13). The experiment was conducted in the laboratory in 6-inch funnels. The soil type was Ruston fine sandy loam. The fertilizers were applied in bands 1¼x5 inches, and with a distance of 1½ inches between bands where two bands were present. Potash was applied at the rate of 100 pounds per acre; superphosphate at the rate of 1,000 pounds per acre, and sulphate of ammonia at the rate of 750 pounds per acre as nitric acid and sulphuric acid, which are formed from sulphate of ammonia in the soil. Only half of the nitrogen was applied, on the assumption that plants would recover half of the nitrogen. The soil was moistened over night, and water equal to a 2-inch rain was leached through it.

Table 13.—THE EFFECT OF PLACEMENT OF FERTILIZERS ON THE LEACHING OF POTASH.

Treatment	Pounds of potash leached per acre	Per cent of applied potash leached
None..	25	..
Potash one side....................................	64	39
Potash one side, nitrogen and phosphate other side.......	72	47
Potash and phosphate one side, nitrogen other side.......	106	81
Potash, nitrogen, and phosphate together...............	111	86
Potassium meta-phosphate one side.....................	26	1
Potassium meta-phosphate one side, nitrogen other side...	40	15
Potassium meta-phosphate and nitrogen one side.........	98	73

Where muriate of potash was applied alone, 39% of the potash was leached out; 47% of the potash was leached out when it was separated from the nitrogen and phosphate by a distance of 1½ inches. When the superphosphate, which contains sulphur in the form of calcium sulphate, was applied in the band with the potash, the loss of potash by leaching increased to 81% of that applied.

Potassium meta-phosphate contains no chlorine or sulphur to leach potash out, and when applied alone, only 1% of its potash leached out; 15% of the potash leached out when nitrogen was added in a separate band. When the nitrogen source containing sulphur was put in the same band with potassium meta-phosphate, 75% of the potash was leached out. From the standpoint of conserving potash in the soil the above data indicate that sulphur should not be applied in contact with potash.

One broadcast application of muriate of potash in one test (12, 13) maintained the yield of cotton equal to that where similar amounts of potash were applied in the drill with other fertilizers each year in another test, nearby in South Carolina (Table 14). When muriate of potash was applied broadcast and the other fertilizers were applied in the drill (Test No. 1), the potash did not come in contact with the sulphates. Since calcium and magnesium chlorides are more soluble than potassium chloride, the chlorine in the muriate of potash was probably lost as calcium and magnesium chlorides, leaving the potash on the clay. Under these conditions, the potash applied in the 100 pounds of muriate of potash stayed in the soil and increased the yield for 7 years. The broadcast applications of potash produced good increases in yield on the tenth year after application.[1]

[1]Personal communication from H. P. Cooper.

Table 14.—THE EFFECT OF METHOD OF APPLICATION ON THE RESPONSE OF COTTON TO POTASH.

Pounds of muriate of potash per acre	Increase in yield of seed cotton—pounds per acre									Per cent recovery of potash estimated
	1931	1932	1933	1934	1935	1936	1937	1938	Ave.	
	Test No. 1—potash broadcast in 1932[1]									
100.................	...	424	423	304	405	192	240	265	336	46
200.................	...	806	621	538	850	450	484	378	589	41
400.................	...	860	855	581	1007	564	846	663	768	27
	Test No. 2—potash applied annually[2]									
64 unlimed.........	216	199	313	144	218	197	208	297	224	7
64 limed...........	404	465	354	344	345	296	251	345	350	11
128 unlimed........	291	258	327	195	277	285	243	384	282	4
128 limed..........	493	660	405	421	468	357	263	374	430	7
192 unlimed........	237	359	163	395	327	368	250	316	302	3
192 limed..........	416	736	518	675	521	455	251	420	499	5

[1] 600 pounds of 5-10-0 fertilizer was applied in the drill annually.
[2] 800 pounds of 8-8-0 fertilizer was applied in the drill annually.

When muriate of potash was applied in contact with the other fertilizers containing sulphates (Test No. 2.), the potassium which was not taken up by the plant was probably leached out of the soil as potassium sulphate, and potash had to be applied annually to maintain crop yields. The response to the annual application of potash did not increase as time went on, which indicates that the annual applications of potash with the other fertilizers did not result in an accumulation of potash in the soil. If the potash was not leached out by the sulphate, when placed in contact with the other fertilizers, the annual applications should have increased the available potash in the soil, and more response to the annual applications of potash should have been obtained from the lower rates during the last years of the test, but this did not occur.

One broadcast application of 100 pounds of muriate of potash increased the yield more in test No. 1 than 7 annual applications of 192 pounds each without lime in test No. 2.

Broadcast applications of potash have not been as effective as drilled applications in tests conducted by the author. Even though the data presented above on broadcast applications of potash are very interesting, additional information will be necessary before broadcast applications of potash can be generally recommended for row crops.

The amount of sulphur required for cotton production[1] (14) can be supplied by 50 pounds of superphosphate or 20 pounds of sulphate of ammonia. According to the data on the depletion of potash by sulphur, no more than this amount of sulphur should be used. The additional phosphorus and nitrogen should come from sources which do not contain sulphur.

The use of lime reduces leaching of potash where sulphate of of ammonia is used. However, less potash was lost by leaching where nitrate of soda was applied than where sulphate of ammonia and lime (5) were applied:

Pounds of lime applied per acre	Pounds of potash leached per acre		
	No nitrogen	Sulphate of ammonia	Nitrate of soda
3,560	61	147	33
7,130	75	70	29
9,920	68	47	30
14,260	47	40	27

[1]Preliminary data from Alabama.

Lime reduced the loss of potash by leaching, but very high amounts of lime did not overcome the increased loss produced by sulphate of ammonia over nitrate of soda. Potash costs about 20 times as much as lime, and the potash lost by leaching where high amounts of fertilizers are used is probably much more valuable than the lime lost by leaching. Nitrate of soda protected the available potash in the soil. These data suggest that the use of neutral fertilizers containing sulphate of ammonia and dolomite will require the use of more potash than where nitrate of soda is the source of nitrogen.

The reason for broadcast application of potash increasing the yield of cotton for 8 or more years is suggested by the data presented in Table 15. The data reported were obtained from 6-inch funnels in

Table 15.—THE EFFECT OF PLACEMENT OF FERTILIZER SALTS ON LEACHING OF POTASH.

No.	Treatment per acre	Potash leached pounds per acre	Increased loss per acre due to treatment
1	No treatment..............................	15.9	....
2	100 lbs. potash as muriate of potash broadcast.	17.6	1.7
3	100 lbs. potash drilled......................	35.2	19.3
4	100 lbs. potash broadcast and 1000 lbs. 20% superphosphate...........................	50.4	34.5
14	100 lbs. potash and 1000 lbs. 20% superphosphate drilled together....................	88.4	72.5

which the soil was 2½ inches deep. Where potash was broadcast it did not leach out of the soil; where it was drilled with superphosphate most of it leached out when 2 inches of rain leached through the soil.

The data in Table 16 on the effect of fertilizers on the leaching of potash may explain the reasons for many of the differences in yields reported in Chapter 1. The data were collected from soil in 6-inch funnels with soil 2½ inches deep where 2 inches of water was leached through the soil. Without the application of potash 16 pounds of potash per acre was leached out. Where 100 pounds of potash per acre was applied in the drill, 19 pounds, or 19% of the applied potash, leached out of the soil.

When nitrogen was added as the nitrate, only 3% of the potash leached out where nitrate of soda was used, 11% where calcium nitrate was used, and 21% where ammonium nitrate was used. The smaller amount of potash leached where nitrate of soda was used suggests one

reason for the superiority of nitrate of soda to calcium nitrate, ammonium nitrate and other sources of nitrogen (Chapter 1) on soils low in potash.

Table 16.—THE EFFECT OF FERTILIZERS ON LEACHING OF POTASH WHEN ALL FERTILIZERS WERE DRILLED.[1]

No.	Treatment per acre	Potash leached pounds per acre	Increased loss of potash due to treatment	Increase in per cent of applied potash leached
		The effect of potash		
1	No treatment......................	16	..	..
2	100 lbs. potash as muriate of potash...	35	19	..
		The effect of nitrates		
7	100 lbs. potash and 150 lbs. nitrogen as nitrate of soda.................	38	22	3
6	100 lbs. potash and 150 lbs. nitrogen as calcium nitrate	46	30	11
5	100 lbs. potash and 150 lbs. nitrogen as ammonium nitrate...............	56	40	21
		The effect of ammonia fertilizers		
10	100 lbs. potash and 150 lbs. nitrogen as ammonia........................	23	7	−12
5	100 lbs. potash and 150 lbs. nitrogen as ammonium nitrate...............	56	40	21
11	100 lbs. potash and 150 lbs. nitrogen as ammonium phosphate............	66	50	31
8	100 lbs. potash and 150 lbs. nitrogen as ammonium sulphate..............	72	56	37
9	100 lbs. potash and 150 lbs. nitrogen as ammonium chloride..............	76	60	41
		The effect of phosphates		
12	100 lbs. potash as potassium phosphate.	35	19	0
13	100 lbs. potash and 200 lbs. phosphate as monocalcium phosphate.........	62	46	27
11	100 lbs. potash and 150 lbs. nitrogen as ammonium phosphate............	66	50	31
14	100 lbs. potash and 1000 lbs. 20% superphosphate..................	88	72	53

[1]Unpublished data from a thesis by Fred H. Haskin.

Ammonia nitrogen alone reduced the leaching of potash 12 pounds per acre, but when the ammonia was added in other forms, greater losses occurred; with ammonium nitrate 21%, ammonium phosphate 31%, ammonium sulphate 37%, and ammonium chloride 41% of the applied potash was lost in the leaching water. With ammonia constant,

the nitrate increased the loss of potash 33%; the sulphate increased the loss 49%; and the chloride increased the loss 53% of the applied potash.

When monocalcium phosphate was used, 27% of the applied potash leached out, and where superphosphate, which is a mixture of mono-calcium phosphate and calcium sulphate, was used, 63% of the applied potash was leached out. The calcium sulphate in superphosphate in-creased the loss of potash by 36 (63-27) pounds per acre, which suggests that only minimum amounts of calcium sulphate should be present in fertilizers. The above data suggest that potash should not be applied in contact with other fertilizers.

The effect of salts on the leaching of potash as reported above is apparently substantiated by observations made in Alabama on cotton rust, which is a symptom of potash deficiency (10). "In some experi-ments on the Alabama substations, cotton fertilized with ammonium sulphate as the source of nitrogen rusted much more readily than adjacent plots fertilized with sodium nitrate. In fact, on certain soils, such as the Clarksville series, the use of ammonium sulphate as the source of nitrogen is avoided by many farmers because they believe that it increases the severity of cotton rust. Cotton that receives large amounts of phosphate frequently rusted more severely than cotton on adjacent plots which received less." The observations suggest (to the author) that the increased rust was due to the sulphate in sulphate of ammonia and calcium sulphate in the superphosphate leaching potash out of the soil.

The potash requirement of cotton was slightly less with fertilizers neutralized with dolomitic limestone (8) than for acid-forming fertil-izers, according to the data (3-year average) reported in Table 17.

Table 17.—THE EFFECT OF DOLOMITE ON THE RESPONSE OF COTTON TO POTASH.

	Pounds of potash per acre		
	18	36	54
	Increase in yield over no potash—pounds seed cotton per acre		
Acid forming fertilizer......	460	566	600
Fertilizer neutralized with dolomitic limestone.....	429	545	562

These data suggest that the use of dolomitic limestone in mixed fertil-izers does not reduce the loss of potash by leaching to a large extent.

The addition of lime which is mixed with all of the soil reduces the leaching of potash. The addition of lime in cyanamid, in contact with all of the fertilizer, decreased the available potash in the Alabama experiments. The potash taken up by the plant and returned to the soil in crop residues is returned in such a manner that it is not immediately in contact with the salts applied in the recent applications of fertilizer; this potash should be subject to leaching to a smaller extent than that which remains adjacent to the other fertilizer salts, and potash returned to the soil in crop residues should be retained by the soil to a greater degree than the potash which remains unused in the fertilizer zone.

The effect of soda upon the physical properties of the soil has been recognized for a long time. When clay has considerable soda on it, granules fail to form, the soil puddles easily and forms hard clods when worked too wet. Under conditions of low rainfall and where amounts of nitrate of soda are used which would be impractical on the farm, the sodium in nitrate of soda may cause the clay particles to separate from one another and move into the subsoil, where a more compact subsoil is formed. Soda causes clay particles to stay in suspension in water when any significant quantity is present on the clay. Data collected by the Alabama Experiment Station (9) show that the amount of soil which remained in suspension after stirring was not affected by nitrate of soda applied at the rate of 45 pounds of nitrogen per acre each year for six years.

At the Mississippi Agricultural Experiment Station unpublished data show that soda does not accumulate in the field where nitrate of soda is used. Soda is very soluble, and with the high rainfall in the Southeast, where much fertilizer is used, nitrate of soda used for field crops should not make a soil more compact nor increase the clods formed in plowing. Farmers have reported the formation of hard clods where nitrate of soda is hill dropped as a side dressing for corn. The hard clods are noticed where the land is not plowed until it gets very dry. The concentration of soda where nitrate of soda is applied in the hill is probably sufficient to cause the hard clods to form. No harmful results could be observed after breaking the land.

The depth of leaching of lime by acid fertilizers (9) is shown by data in Table 18. The use of sulphate of ammonia lowered the base content of the Alabama soil very definitely to 16 inches below the surface and slightly to the 16 to 20 inch layer. With the use of less sulphate of ammonia on the Georgia soil, the depletion of bases had not taken place below the 8-inch depth. Upon the basis of the data

presented, it appears that acid fertilizers remove the bases from the top soil first, after which they deplete the sub-soil of its bases.

Table 18.—THE DEPTH TO WHICH SULPHATE OF AMMONIA LEACHES LIME OUT OF THE SOIL.

Depth	Location of test plots			
	Auburn, Alabama[1]		Athens, Georgia[2]	
	Check	Sulphate of ammonia	Check	Sulphate of ammonia
Inches	pH	pH	pH	pH
0-4	5.40	4.55	5.00	4.60
4-8	5.40	4.55	5.00	4.60
8-12	5.00	4.55	5.05	5.05
12-16	4.95	4.85	5.35	5.35
16-20	4.85	4.80	....	....

[1] 3,150 lbs. of sulphate of ammonia applied over a 15-year period; Cecil sandy loam.
[2] 1,540 lbs. of sulphate of ammonia applied over a 12-year period; Cecil sandy loam.

SUMMARY AND CONCLUSIONS

Superphosphate and muriate of potash exert little influence on the lime content of the soil. Sources of nitrogen exert a tremendous effect on the lime and potash content of the soil. Unused nitrogen leaches lime and potash out of the soil, while a much greater influence is exerted by the basic elements like potash, calcium, and soda, and the acid elements like sulphur, chlorine, and phosphorus, with which the nitrogen is combined. In so far as the elimination of sulphur is in keeping with economical fertilizer production, it appears that only the sulphur required by crops should be contained in fertilizers.

The data reviewed in this chapter on the effect of fertilizers upon the soil show that:

1. Sulphate of ammonia, leunasalpeter, and ammo-phos A depleted the lime content of the soil rapidly.
2. Organic sources of nitrogen depleted the calcium and magnesium contents of the soil.
3. Nitrate of soda and calcium nitrate had very little influence on the lime content of the soil but tended to maintain or increase it slightly. Cyanamid increased the lime content of the soil.
4. The sulphur applied in fertilizers depleted the potash rapidly, particularly when the potash and sulphur-containing fertilizers were applied together in a band.
5. Superphosphate had very little influence on the lime content of the soil.
6. Lime mixed with all of the soil saved potash; but lime (calcium)

in fertilizers applied in a band apparently did not protect the available potash.

7. Sulphur is a required element. The sulphur needs of cotton probably can be obtained from 50 pounds of superphosphate, or 20 pounds of sulphate of ammonia.

8. Muriate of potash applied broadcast increased the yield of cotton for at least 7 years in one test. It had very little lasting effect where applied in the drill with fertilizers containing considerable sulphur.

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Calculating the Effect of Fertilizers on the Lime Content of Soils

Unharvested nitrogen, sulphur, and chlorine leach lime and potash out of the soil.

Growing plants take carbon dioxide out of the air, heat from the sun, and water out of the soil and combine them to make carbohydrates. The carbohydrates are used for energy, or are converted into starches, fats, and proteins, which become a part of the plant. In this process oxygen is released into the air. In the manufacture of proteins, nitrogen, phosphorus, and sulphur are combined with carbohydrates. Calcium exists in the cell walls. Magnesium, phosphorus, nitrogen, and other elements are in the green colored material of the plant leaves. Potash and soda are present throughout the plant, and their function is not well known.

In addition to the above elements, plants contain small amounts of most of the mineral elements found in the soil, the most important of which are iron, aluminum, copper, zinc, boron, silicon, sulphur, and manganese. Growing plants take simple elements and use them to build complex plant material.

When plant material or organic fertilizers are added to the soil, decomposition takes place. Decomposition of plants is the opposite of plant growth. In general, the decomposition of organic matter produces the same end products as burning the material. In decomposition, oxygen is used up; heat is given off; carbon dioxide is formed; and all of the elements which plants obtain from the soil are returned to it. The elements returned to the soil are nitrogen, phosphorus, potash, sulphur, iron, aluminum, silicon, calcium, magnesium, manganese, soda, zinc, boron, copper, and others. From the standpoint of cost and scarcity nitrogen is the most important element given back to the soil in the decomposition of organic matter. Upon decomposition of the plant material nitrogen is released as ammonia.

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Ammonia nitrogen combines with the clay to form ammonia clay, in which form it does not leach out of the soil readily. Plants may use ammonia nitrogen without change. The grasses and young plants, particularly cotton and corn, prefer ammonia nitrogen. Ammonia nitrogen stays in fertile soils only a short time before it is changed into nitrate nitrogen. Ammonia nitrogen first goes into the soil solution and takes up water to form ammonia water (ammonium hydroxide), after which it takes up carbon dioxide to form ammonium carbonate, releasing part of the water taken up. There are bacteria which use ammonium carbonate for energy, and in the process oxygen is added and water and nitrite nitrogen are formed, after which other bacteria use the nitrite nitrogen to get energy, and more oxygen is added and nitrate nitrogen is formed.

The decomposition processes take place much more rapidly in fertile soils than in poor soils, and ammonia nitrogen is changed to nitrate nitrogen much more rapidly in fertile soils than in poor soils. In the spring most ammonia nitrogen is converted into nitrate nitrogen within 30 to 60 days. Many poor soils are so low in lime and phosphate that the decomposition of green manure crops and the formation of ammonia nitrogen is too slow for the following crop to receive maximum benefit from the green manure.

Nitrate nitrogen combines with the bases on the clay to form calcium nitrate, magnesium nitrate, nitrate of soda, and nitrate of potash, etc. When the nitrate nitrogen pulls calcium, magnesium or potash off the clay, hydrogen takes their places, and the clay becomes acid. The nitrates stay in the soil solution until they are used by growing plants, or they leach out of the soil in the drainage water. When they leach out, the soil loses the potash, soda, and lime, which are combined with the nitrogen. The leaching of nitrate nitrogen in humid climates makes it necessary to turn legumes into the soil or add commercial nitrogen regularly to produce good crops.

The loss of bases by nitrate nitrogen leaching them out helps to keep humid soils low in lime and other bases where legumes are turned under, or nitrogen is applied to the soil. In soils high in lime each pound of nitrogen leached will take 3.57 pounds of lime out of the soil. Lime is not the only base lost by leaching of nitrate nitrogen, but the loss of lime may be used to give a picture of what takes place. The loss of magnesium as magnesium nitrate is considerable, but due to the fact that soils usually contain much more calcium than magnesium, more calcium than magnesium is lost by the leaching of nitrate nitrogen. The loss of potash as potassium nitrate when green manures are turned

into the soil or nitrogenous fertilizers are used should be negligible where the calcium and magnesium content of the soil is high; however, the loss of potash is much greater where the calcium and magnesium contents of the soil are low.

Before urea nitrogen can be used by crops it must be changed into ammonia nitrogen. Bacteria in the soil change urea nitrogen into ammonia nitrogen, and in the process they get energy for their life processes. The ammonia goes onto the clay. The ammonia nitrogen may be used as such, or it may be changed to nitrate nitrogen, after which it reacts with the soil bases on the clay to form nitrate of soda, calcium nitrate, magnesium nitrate, potassium nitrate, and acid clay.

Cyanamid reacts with water to form urea. The urea nitrogen formed from cyanamid goes through the same changes as discussed for urea above. As was pointed out in Chapter 3, other reactions may take place with cyanamid.

Sulphate of ammonia reacts with calcium clay to form ammonia clay, and calcium sulphate. A small amount of ammonia goes into the soil solution, forming acid clay and ammonia water (ammonium hydroxide), which is changed to ammonium carbonate, from which the plants may get ammonia nitrogen. The ammonium carbonate is usually changed to nitrate nitrogen in fertile soils in a short time, after which the nitrate nitrogen reacts with calcium clay to form calcium nitrate and more acid clay.

The calcium in pure calcium nitrate is equal to 3.57 pounds of pure lime (calcium carbonate) per pound of nitrogen present. Where calcium nitrate contains 15% nitrogen, it contains calcium equal to 15 x 3.57 or 53.6 pounds of pure lime per 100 pounds of material. The old-style calcium nitrate was a neutral salt, made by adding lime to nitric acid. The calcium nitrate on the market in recent years contains a little ammonium nitrate. It takes 3.57 pounds of pure lime to change one pound of nitrogen into calcium nitrate.

Sulphate of ammonia contains nitrogen and sulphur, which are acid forming. To convert the nitrogen in sulphate of ammonia containing one pound of nitrogen into calcium nitrate requires 3.57 pounds of pure lime. It also requires 3.57 pounds of pure lime to convert the sulphate in sulphate of ammonia containing one pound of nitrogen into calcium sulphate. It, therefore, takes 3.57 plus 3.57 or 7.14 pounds of pure lime to convert sulphate of ammonia containing one pound of nitrogen into calcium nitrate and calcium sulphate. To convert 100 pounds of sulphate of ammonia into calcium nitrate and calcium sulphate requires 20.5 x 7.14 or 146 pounds of pure lime. When enough

lime is added to convert sulphate of ammonia to calcium nitrate and calcium sulphate, it will have the same effect upon the total bases in the soil as nitrate of soda and calcium nitrate; however, in the process, potash, which is expensive, is lost to a smaller extent where nitrate of soda or calcium nitrate is used.

The soda in nitrate of soda carrying one pound of nitrogen is equal to 3.57 pounds of pure lime. One hundred pounds of nitrate of soda contains soda equal to 3.57 x 16 or 56.9 pounds of lime. The soda in nitrate of soda leaches out of the soil in the drainage water instead of lime and potash. Where carbonated water is removing bases from the soil, which is happening in most soils, the use of nitrate of soda reduces the leaching of lime and potash. Soda should protect potash where sulphur is leaching bases out of the soil, due to the high solubility of sodium sulphate. The use of nitrate of soda, therefore, tends to keep potash, calcium, and magnesium from leaching out of the soil.

Ammo-phos A (ammonium phosphate) contains 11% nitrogen and 46% phosphate. As is the case with sulphate of ammonia, ammo-phos A has only acid-forming elements present. 3.57 pounds of pure lime is required for each pound of nitrogen, and 0.71 pounds of pure lime for each pound of phosphate present. 100 pounds of ammo-phos A requires 11 x 3.57 or 39.27 pounds of lime to make calcium nitrate of the nitrogen, and 46 x 0.71 or 32.66 pounds of lime to make the phosphorus non-acid-forming, or a total of 72 pounds of lime per 100 pounds of ammo-phos A.

Diammonium phosphate contains 21% nitrogen and 53% phosphate. The nitrogen requires 21 x 3.57 or 75 pounds of lime, and the phosphorus requires 53 x 0.71 or 38 pounds of lime to make neutral salts. The lime required to make neutral salts out of 100 pounds of diammonium phosphate is 75 plus 38 or 113 pounds.

Ammonium nitrate contains 32½% nitrogen. Ammonium nitrate contains only nitrogen which influences the lime content of the soil. Since each pound of nitrogen requires 3.57 pounds of lime to convert it into calcium nitrate, 100 pounds of ammonium nitrate requires 32½ x 3.57 or 116 pounds of lime to convert it into calcium nitrate.

Ammonia contains 82.2% nitrogen. It takes 3.57 pounds of pure lime to convert each pound of nitrogen into calcium nitrate. Multiplying 82.2 x 3.57 gives 293 pounds of lime required to make calcium nitrate out of 100 pounds of ammonia.

Calcium nitrate fertilizer is largely calcium nitrate, but it has a little ammonium nitrate in it. It contains 15% nitrogen. The calcium in pure calcium nitrate balances the nitrate nitrogen. One pound of nitrogen in commercial calcium nitrate requires 0.42 pounds of lime per

pound of nitrogen present to make calcium nitrate out of the ammonium nitrate. Multiplying 15 x 0.42 gives 6 pounds of lime necessary to add with 100 pounds of calcium nitrate to make calcium nitrate out of all of the nitrogen.

Calnitro is a mixture of ammonium nitrate and lime. There is a

Table 1.—LIME NECESSARY TO MAKE LIME SALTS OUT OF FERTILIZERS, AND THE LIME REQUIRED TO MAKE NEUTRAL FERTILIZERS ACCORDING TO THE OFFICIAL METHOD.

Material	Per cent nitrogen	Pure lime necessary to make lime salts[1]			Pounds pure lime; official method for neutralizing fertilizers		
		Per pound of nitrogen	Per 20 pound of nitrogen	Per 100 pound of material	Per pound of nitrogen	Per 20 pound of nitrogen	Per 100 pound of material
Inorganic sources of nitrogen							
Sulphate of ammonia	20.5	7.14	143	146	5.35	107	110
Ammo-phos A	11.0	6.77	135	74	5.00	100	55
Anhydrous ammonia	82.2	3.57	72	293	1.80	36	148
Calcium nitrate	15.0	0.42	8	6	1.35B	27B	20B
Calnitro	16.0	0.66	13	11	1.31B	26	21
Calnitro	20.5	1.77	35	36	0	0	0
Crude nitrogen solution	44.4	2.98	60	132	1.20	24	53
Nitrate of soda	16.0	0.00	0	0	1.80B	36B	29B
Potassium nitrate	13.0	0.00	0.00	0.00	2.00B	40B	26B
Manufactured organic nitrogen							
Cyanamid	22.0	1.18B	24B	26B	2.85B	57B	63B
Urea	46.6	3.57	71	166	1.80	36	84
Urea-ammonia liquor	45.5	3.57	71	162	1.80	36	82
Natural organic nitrogen							
Cocoa shell meal	2.7	2.37	47	6	0.60B	12B	2B
Castor pomace	4.8	2.67	53	13	0.90	18	4
Cottonseed meal	6.7	3.17	63	21	1.40	28	9
Dried blood	13.0	3.52	70	46	1.75	35	23
Fish scrap	9.2	2.67	53	25	0.90	18	8
Fish scrap	8.9	1.78	36	16	0.01	2	0
Guano, Peruvian	13.8	2.72	54	38	0.95	19	13
Guano, white	9.7	2.22	44	21	0.45	9	4
Milorganite	7.0	3.47	69	24	1.70	34	12
Tankage, animal	9.1	1.92	38	17	0.15	3	1
Tankage, garbage	2.5	0.93B	19B	2B	2.70B	54B	7B
Tankage, high grade	8.4	2.52	50	21	0.75	15	6
Tankage, low grade	4.3	5.43B	109B	23B	7.20B	144B	31B
Tankage, packing house	6.0	0.12	2	1	1.65B	33B	10B
Tankage, process	7.4	3.32	66	25	1.55	31	12
Tobacco stems	1.4	16.03B	321B	22B	17.80B	356B	25B
Tobacco stems	2.8	2.53B	51B	7B	4.30B	86B	12B
Sources of potash							
Manure salts	0	0	0	0	0	0	0
Muriate of potash	0	0	0	0	0	0	0
Potassium nitrate	13.0	0	0	0	2.00B	40B	26B
Sulphate of potash	0	0	0	0	0	0	0
Sulphate of potash—magnesia	0	0	0	0	0	0	0
Sources of phosphorus							
Ammo-phos A	11.0	6.77	135	74	5.00	100	55
Precipitated bone	0	0	0	0	0	0	29B
Superphosphate	0	0	0	0	0	0	0
Triple superphosphate	0	0	0	0	0	0	0

[1]Data to make lime salts from organic sources of nitrogen were obtained by adding 1.77 pounds per pound of nitrogen to data for neutral fertilizers (3).
B=lime in excess of that required to make neutral salts or neutral fertilizers.

16% and a 20.5% nitrogen calnitro. The 20.5% material needs 1.77 pounds of lime per pound of nitrogen or 36 pounds of lime per 100 pounds of material to convert the nitrogen into calcium nitrate. The 16% calnitro requires 11 pounds of lime per 100 pounds to convert the nitrogen into calcium nitrate.

Crude nitrogen solution is a mixture containing 7.4% nitrogen from nitrate of soda and 37% nitrogen from ammonia. Crude nitrogen solutions require 2.98 pounds of lime per pound of nitrogen or 132 pounds per 100 pounds of material to convert the ammonia nitrogen into calcium nitrate.

Potassium nitrate contains 13.2% nitrogen and 44% potash. It has sufficient potash to combine with the nitrate and keep it from making the soil more acid.

Nitrate of soda-potash is a mixture of nitrate of soda and nitrate of potash containing 14% nitrogen and 13 to 14% potash. It has sufficient soda and potash to combine with the nitrogen to make a neutral salt.

Urea-ammonia liquor is a mixture containing 30.4% ammonia nitrogen, and 15.1% urea nitrogen or a total of 45.5% nitrogen in solution. This mixture requires 3.57 pounds of lime per pound of nitrogen or 162 pounds of lime per 100 pounds of material to convert the nitrogen into calcium nitrate.

Cyanamid contains 21 or 22% nitrogen. Cyanamid contains 4.65 pounds of lime for each pound of nitrogen present. 100 pounds of cyanamid contains calcium equal to 22 x 4.65 or 102 pounds of lime. It has 1.08 pounds of lime per pound of nitrogen more than is required to convert the nitrogen into calcium nitrate. Cyanamid containing 22% nitrogen has 22 x 1.08 or 24 pounds of lime per 100 pounds more than is needed to convert the nitrogen into calcium nitrate.

Urea is a manufactured organic nitrogen fertilizer. It contains 46.6% nitrogen, and 3.57 pounds of lime is required to change each pound of nitrogen to calcium nitrate. 100 pounds of urea requires 46.6 x 3.57 or 166 pounds of lime to change it into calcium nitrate. Urea is sold under the trade name "uramon", which contains 42% nitrogen, and a very small amount of dolomite and cocoa shell meal.

The natural organic fertilizer materials, like dried blood and cottonseed meal, are used in fertilizers primarily to improve their physical condition. In addition to nitrogen, they have some calcium, magnesium, potash, soda and a small amount of sulphur, chlorine, and phosphorus. Cottonseed meal containing 6.7% nitrogen will be used to illustrate the calculations on organic materials. Cottonseed meal has

an excess of about 0.4 pounds of lime per pound of nitrogen over acids other than nitrogen. Each pound of nitrogen supplied by cottonseed meal requires 3.57 pounds of lime to convert it into calcium nitrate. Subtracting 0.4 from 3.57 gives 3.17 pounds of lime necessary to add with each pound of nitrogen in cottonseed meal to change it into calcium nitrate. Multiplying 6.7 x 3.17 gives 21 pounds of lime required to change the nitrogen in 100 pounds of cottonseed meal to calcium nitrate.

Triple superphosphate (monocalcium phosphate) contains 0.71 pounds of lime for each pound of phosphate present, which is just sufficient to make it neutral.

Superphosphate is a mixture of calcium sulphate and monocalcium phosphate, in which the lime is sufficient to counteract the acid effects of the sulphate and phosphate.

The effect of sources of nitrogen on the lime and potash content of the soil depends upon what goes with the nitrogen. When one pound of nitrogen in a fertilizer like nitrate of soda is applied to the soil in the absence of plants, it leaches out without changing the lime content of the soil. However, if plants use all of the nitrogen, nearly all of the soda would leach out of the soil instead of lime. The actual effect, therefore, depends upon the amount of applied nitrogen which leaches out of the soil. Most of the nitrogen which leaches out of the soil leaches out as calcium nitrate, magnesium nitrate, and potassium nitrate.

Nitrate of soda contains soda equal to the nitrogen, and in the absence of a growing crop, it neither increases nor decreases the lime content of the soil. In the presence of a growing crop, where part of the nitrogen is removed in the crop, nitrate of soda usually increases the lime content of the soil slightly as is shown by the data (4)[1] on unlimed soil (Table 2).

Nitrate of soda is a source of nitrogen which is supposed to increase the lime content of the soil. The above data, however, show that nitrate of soda increased the lime content of the soil an average of only 0.18 pounds of lime per pound of nitrogen or 58 pounds of lime per ton of nitrate of soda. This increase in lime content of the soil is too small to be significant. The small increase in the lime content of the soil where nitrate of soda was used was due to the soda leaching out with acids in the place of lime. The official method for determining the effect of fertilizers on the lime content of the soil assumes that a ton of nitrate of soda will increase the lime content of the soil 580 pounds, but it

[1]Numbers in parenthesis refer to the source of information, page 121.

actually increased it only 58 pounds in six tests of 16 to 44 years duration.

The lime content of the soil can be increased only slightly with the use of so-called basic sources of nitrogen. Where soils are strongly acid the use of basic sources of nitrogen will never increase the lime content of the soil significantly, even when used over a long period of time. Most of the fertilizers are used in areas where the soils are acid. The use of fertilizers lower in bases than nitrate of soda over a long period of time may not be sound unless lime is used. Since there is an official method for calculating the effect of fertilizers on the lime content of the soil, it is desirable to present data on methods for determining the effect of fertilizers on the lime content of the soil.

Table 2.—THE EFFECT OF NITRATE OF SODA ON THE LIME CONTENT OF SOILS.

Location	Number of years	Pounds of lime[1] gained or lost per pound of nitrogen applied
New Jersey................	18	0.19 loss
New Jersey................	18	0.10 gain
Pennsylvania.............	44	0.10 gain
Pennsylvania.............	44	0.35 gain
Pennsylvania.............	44	0.00
Alabama.................	16	0.70 gain
	Average	0.18 gain

[1]Including potash and magnesium.

The data in Chapter 4 show that calcium nitrate and nitrate of soda barely maintained the lime content of the soil or increased it only slightly. The data from the Rhode Island and Alabama Experiment Stations also show that even with nitrate of soda it is necessary to add lime to maintain the lime content of the soil at a significantly higher level than is natural for the soil. The data in the previous chapter also show that sulphate of ammonia, ammo-phos A, urea, and most organic fertilizers decrease the lime content of the soil.

The present official method of calculating (9) the effect of fertilizers on the lime[1] content of the soil considers that (a) the sulphur, the chlorine, one-third of the phosphorus, and only one-half of the nitrogen reduce the lime content of the soil, and (b) that calcium, magnesium, potash, and soda increase the lime content of the soil.

The official method for determining the effect of fertilizers on the lime content of the soil was worked out by Pierre (8, 9), who based

[1]Including potash and magnesium.

the method on results obtained with mixtures of nitrate of soda and sulphate of ammonia, and lime and sulphate of ammonia. The data on which the method was based were collected under greenhouse conditions where crops were grown with very high amounts of nitrogen. The official method was based upon the following data: (a) 1.2 pounds of lime counteracted the acid effects of 0.205 pounds of nitrogen and the sulphate in one pound of sulphate of ammonia, and (b) a combination of 80 per cent of the nitrogen from nitrate of soda and 20 per cent from sulphate of ammonia caused no change in the pH of one soil and reduced the pH of another soil only slightly. Pierre (8) combined these data and concluded that 51 per cent of the nitrogen was taken up by the plant as nitric acid, and 49 per cent as a salt like calcium nitrate, from which he calculated that one pound of applied nitrogen required 1.8 pounds of lime to counteract its acidity. Careful analysis shows that the conclusion is not in agreement with the data on which it was based.

If it is assumed that the sulphate radical in sulphate of ammonia containing one pound of nitrogen requires 3.57 pounds of lime to counteract its acidity then, where (a) 1.2 pounds of lime counteracted the acid affects of sulphate of ammonia containing 0.205 pounds of nitrogen, each pound of nitrogen required 2.29 pounds of lime to counteract its acidity, and (b) where 80 per cent of the nitrogen from nitrate of soda and 20 per cent from sulphate of ammonia made little or no change in the pH of the soil, each pound of nitrogen required 2.14 pounds of lime equivalent to counteract its acidity. Averaging 2.14 and 2.29 gives a value of 2.22 pounds of lime required to neutralize the acidity of one pound of nitrogen, instead of 1.80 pounds as used in the official method. It is, therefore, evident that the present official method for calculating the effect of nitrogen on the lime content of the soil is not in agreement with the data on which it was supposed to have been based.

Vetch was one of the crops grown. Normally, vetch takes nitrogen out of the air through root nodule bacteria. No account was made of the nitrogen obtained out of the air as a result of growing vetch, nor of the crops grown and the nitrogen and other elements removed in them, which may have markedly influenced the results obtained.

The relative acid effect of sources of nitrogen on soil acidity as found in the original research paper (8) and the calculated relative effects assuming that all nitrogen increases soil acidity, as well as the values used in the official method, are as follows:

Source of nitrogen	Relative acid effects		
	By official method	As found in soil	As found calculating that all nitrogen increases soil acidity
Sulphate of ammonia..........	100	100	100
Leunasalpeter...............	66	83	81
Ammonium nitrate...........	33	50	50
Urea......................	33	53	50

The above data and calculations and those presented on the previous page show:

1. The official method for determining the effect of nitrogen on soil acidity is not in agreement with the data on which it was supposed to have been based.

2. The relative acid effects of sources of nitrogen according to the official method are not in agreement with the relative effects produced in the soil.

3. The effect of sources of nitrogen on soil acidity as reported (8) suggests that all of the nitrogen increased soil acidity.

It appears, therefore, that the present official method for determining the effect of sources of nitrogen on soil acidity was not based on the data reported in the original paper.

Lewis (England) (5) found that the actual effect of the element nitrogen upon the lime content of the soil could be estimated by calculating that the nitrogen which was not recovered by the crop was lost in the drainage water as calcium nitrate. That is, each pound of nitrogen which is not removed in the harvested part of the crop leaches out of the soil and carries 3.57 pounds of lime with it. The estimates agreed closely with the actual loss of bases from the application of sources of nitrogen to the soil under field conditions. The data and estimations of Lewis are in agreement with the conclusion of Morgan and Bailey (7) that, in the absence of growing plants, soils having a good supply of lime (bases) lose approximately 3.57 pounds of lime for each pound of nitrogen applied to the soil.

Andrews and Cowart (1) applied the calculations of Lewis, and the conclusion of Morgan and Bailey to fertilizer and yield data for cotton. They calculated that each pound of nitrogen which was not recovered in the seed cotton leached 3.57 pounds of lime out of the soil, and in addition they found that seed cotton contains an excess

of lime over acids other than nitrogen which should be taken into consideration. The tabulations in Table 3 illustrate the application of the calculations on the effect of sources of nitrogen on the lime content of the soil when applied to soils on which cotton is grown.

Table 3.—CALCULATIONS ON THE AMOUNT OF LIME LOST WHERE UREA, NITRATE OF SODA, AND SULPHATE OF AMMONIA ARE USED FOR COTTON PRODUCTION.

Nitrogen source and calculations	Pounds	Pounds
Urea		
Nitrogen applied...............................	...	30.00
Increase in yield of seed cotton....................	291	.....
Nitrogen in seed cotton (291×2%).................	...	5.82
Nitrogen not recovered (30−5.82).................	...	24.18
Lime lost with unrecovered nitrogen (24.18×3.57)....	...	86.32
Excess of lime (bases) over acids in seed cotton		
(291×0.87%).................................	...	2.53
Total lime lost.................................	...	86.85
Lime lost per pound of nitrogen applied (86.85÷30)..	...	2.96
Nitrate of soda		
Nitrogen applied...............................	...	30.00
Lime applied (as soda) (30×3.57).................	...	107.10
Increase in yield of seed cotton....................	337	.....
Nitrogen in seed cotton (337×2%)	...	6.74
Nitrogen not recovered (30−6.74).................	...	23.26
Lime lost with un-recovered nitrogen (23.26×3.57)....	...	83.03
Excess of lime (bases) over acids in seed cotton		
(337×0.87%).................................	...	2.93
Total lime lost (83.03+2.93).....................	...	85.96
Total lime gained (107.1−85.96)..................	...	21.04
Lime gained per pound of nitrogen applied (21.04÷30).	...	0.70
Sulphate of ammonia		
Nitrogen applied...............................	...	30.00
Increase in yield of seed cotton....................	301	.....
Nitrogen in seed cotton (301×2%).................	...	6.02
Nitrogen not recovered (30−6.02).................	...	23.98
Lime lost with nitrogen (23.98×3.57)..............	...	85.57
Lime lost with sulphate (30×3.57).................	...	107.10
Excess of lime (bases) over acids in seed cotton		
(301×0.87%).................................	...	2.60
Total lime lost (85.57+107.1+2.6)................	...	195.37
Lime lost per pound of nitrogen applied (195.3÷30)...	...	6.51

The data of the Alabama Agricultural Experiment Station (10) on the effect of sources of nitrogen on the yield of seed cotton and on the lime content of the soil were used to compare three methods of determining the effect of sources of nitrogen on the lime content of the soil. The data obtained were calculated to pounds change in lime

per pound of nitrogen applied on the basis of 2,000,000 pounds of soil being affected. The data are reported in Table 4.

The effect of sources of nitrogen on the lime content of the soil can be determined accurately only where the lime content is maintained at a constant level (2). Where the lime content of the soil is increasing due to the treatment, a greater natural loss of lime occurs,

Table 4.—COMPARISONS OF THE EFFECT OF SOURCES OF NITROGEN ON THE LIME CONTENT OF THE SOIL AND METHODS OF CALCULATING THEIR EFFECT.

Source of nitrogen	Lime gained or lost per pound of nitrogen applied		
	Soil	Calculated from unrecovered nitrogen and extra lime in plants	Official method
	Lime lost by acid fertilizers		
Nitrate of soda 3/5, sulphate of ammonia 2/5........................	0.52	1.89	1.09
Urea.............................	2.66	2.11	1.43
Sulphate of ammonia	5.69	6.20	5.35
Ammo-phos A.....................	5.17	5.84	5.00
Leunasalpeter....................	4.33	4.44	3.54
Cottonseed meal..................	1.11	2.34	1.40
Average loss.....................	3.25	3.80	2.97
	Lime gained from basic fertilizers		
Cyanamid........................	2.00	1.41	2.46
Nitrate of soda....................	0.33	0.94	1.80
Calcium nitrate...................	0.00	0.62	1.35
Average gain.....................	0.78	0.99	1.87
Average of averages—loss..........	1.24	1.41	0.55

These calculations are a rearrangement of the original data from Proc. Soil. Sci. Soc. of Amer. 4:275-280 (1). 1939.

due to a greater loss of lime in the drainage water as bicarbonate of lime. Where the lime content of the soil is decreasing due to the treatment, the natural loss of lime is decreased, due to a smaller loss as bicarbonate of lime.

When the lime content of the soil is decreasing, due to the use of acid-forming sources of nitrogen, the decrease is much less than the calculated amount. According to the official method sulphate of am-

monia should reduce the lime (total bases) 5.4 pounds per pound of nitrogen applied.

Where sulphate of ammonia was applied in 9 experiments over a period of 13 years in Alabama (1), only 1.07 pounds of lime was lost as compared to the loss of 5.4 pounds according to the official method. Where nitrate of soda was used, the gain was 0.47 pounds of lime equivalent per pound of nitrogen applied as compared to 1.8 pounds gain according to the official method.

The above data suggest that experiments for determining the effect of sources of nitrogen on the lime content of the soil are unreliable unless the lime content of the soil is exactly maintained by applications throughout the duration of the experiment.

Where acid-forming sources of nitrogen were applied in the Alabama experiments, an attempt was made to maintain the base content of the soil by adding lime (Table 4). The average loss of lime was 3.25 pounds per pound of nitrogen applied. Since these treatments did not maintain the lime content of the soil, the loss of 3.25 pounds of lime per pound of nitrogen in the different sources applied to the soil is too low. Had the lime content of the soil been maintained, the loss would have been greater, and probably would have approached the average calculated loss of 3.80 pounds of lime per pound of nitrogen. The theoretical loss according to the official method was 2.97 pounds of lime per pound of nitrogen applied.

Where the treatments were increasing the lime content of the soil, the soils gained slightly less than the calculated amount of lime per pound of nitrogen applied in the different sources, and they gained very much less than was calculated by the official method. The soils gained 0.78 pounds; the calculated gain was 0.99 pounds; and the official method indicates they should have gained 1.87 pounds of lime per pound of nitrogen applied. Averaging all of the data on the different sources of nitrogen, the soil lost 1.24 pounds of lime per pound of nitrogen applied; the calculated loss on the basis of the unharvested nitrogen leaching out of the soil as calcium nitrate and the extra lime in the harvested part of the plant was 1.41 pounds of lime. The average loss from the soil was very close to the calculated loss. The official method indicates that the soils should have lost an average of only 0.55 pounds of lime per pound of nitrogen applied; whereas, they actually lost 1.24 pounds. The difference between the effect of sources of nitrogen for cotton production on the lime content of the soil and the official method for calculating their effect on the lime ontent of the soil appears to be too large for neutral fertilizers, accord-

ing to the present official method, to be non-acid forming when used for cotton production.

Lime was applied to maintain the lime content of the soil according to the official method in five experiments of 9 to 13 years duration. Cotton and corn were grown in rotation in Alabama (11). The average decrease in lime content of the soil for four acid-forming sources of nitrogen was 0.74 pounds of lime per pound of nitrogen applied. The data suggest that the official method should require 1.80 + 0.74 or 2.54 pounds of lime per pound of nitrogen instead of 1.8 as now required.

Table 5.—THE EFFECT OF SOURCES OF NITROGEN ON THE YIELD OF SEED COTTON AND ON THE BASE SUPPLY OF THE SOIL.

Source of nitrogen	Alabama									Miss. Delta
	Soil group and number of tests									
	Clarkesville	Decatur	Holston	Hartselle	Cecil	Oktibbeha	Greenville	Norfolk	General average	Alluvial
	10	32	21	36	17	15	34	57	222	5
	Increase in pounds of seed cotton per acre									
Nitrate of soda	312	284	417	365	363	221	374	320	337	416
Sulphate of ammonia...	270	249	336	364	361	158	362	262	301	330
Urea.........	226	284	339	318	317	175	331	265	291	318
Cottonseed meal.......	220	139	263	175	226	21	235	205	192	...
Cyanamid....	...	...	...	...	...	...	...	...	...	321
Calcium nitrate.....	...	...	...	...	...	...	...	...	...	345
Calnitro......	...	...	...	...	...	...	...	...	...	349
	Calculated effect of 1 pound of nitrogen in different sources on lime content of soil									
Nitrate of soda	0.65B[1]	0.59B	0.87B	0.76B	0.76B	0.46B	0.78B	0.67B	0.70B	0.87B
Sulphate of ammonia...	6.58A	6.62A	6.44A	6.38A	6.39A	6.81A	6.38A	6.59A	6.51A	6.45A
Urea.........	3.10A	2.98A	2.86A	2.91A	2.91A	3.20A	2.88A	3.02A	2.96A	2.91A
Cottonseed meal.......	2.71A	2.88A	2.62A	2.80A	2.70A	3.13A	2.68A	2.74A	2.77A	.....
Cyanamid....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.75B
Calcium nitrate.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28B
Calnitro......	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.07B

[1]B = base. A = acid-producing.

If the loss of lime were calculated on the basis of nitrogen not harvested leaching 3.57 pounds of lime per pound of nitrogen out of the soil and the bases removed in the seed cotton, 0.83 pounds of lime should have been lost, which would make each pound of nitrogen require 2.62 (1.79 + 0.83) pounds[1] of lime. The agreement between the

[1]The excess bases in the increase in corn yield was assumed to be 4.52 pounds of lime, which is the same as that in cotton.

actual loss (including 1.8 pounds lime per pound of nitrogen actually used) of 2.54 pounds and the calculated loss of 2.62 is close. The difference between these values and the official method, which requires 1.8 pounds of lime per pound of nitrogen, is too large to be overlooked.

The increases in yield of seed cotton produced by the sources of nitrogen in the tests upon which the above calculations were made were larger than are obtained normally. The data presented in Table 5 may be more nearly representative of what farmers are actually getting, since they are based on averages for 222 field tests. The calculated effect of the different sources of nitrogen upon the base content of the soil for cotton production in the field was compared to the official method. Part of the comparison of calculated effects of nitrogen sources on the base content of the soil under field conditions and the official method is shown in Table 6. The calculations suggest that "non-acid forming" or "neutral" fertilizers for cotton production will increase soil acidity, though the increase in acidity is much less than if no lime were used.

The effects of nitrogen sources on the lime content of the soil were calculated on the basis of 30 pounds of nitrogen in all sources of nitrogen increasing the yield 337 pounds of seed cotton per acre, which was the average for nitrate of soda in 222 experiments in Alabama. The calculations are in error to the extent that other sources of nitrogen fail to increase the yield as much as nitrate of soda. The calculations are reported in Table 7.

Dolomitic limestone may be used to replace sand as filler in low analysis fertilizers. The most commonly used fertilizer in the Southeast before the war was a 4-8-4. If 4 tons of acid 5-10-5 fertilizer is diluted with one ton of dolomite to make 5 tons of neutral 4-8-4 fertilizer, the dolomite obtained in this manner costs the farmer about

Table 6.—METHODS OF CALCULATING THE EFFECT SOURCES OF NITROGEN ON THE LIME CONTENT OF THE SOIL.

Source of nitrogen (222 tests)	Loss or gain of lime per pound of nitrogen	
	Calculated on basis of loss of nitrogen as calcium nitrate and extra lime in harvested seed cotton	Official method
Nitrate of soda	0.70 gain	1.8 gain
Sulphate of ammonia	6.51 loss	5.4 loss
Urea	2.96 loss	1.8 loss
Cottonseed meal	2.77 loss	1.4 loss

$15.00 per ton. The dolomitic lime could be bought for approximately $4.00 per ton. If higher analysis acid fertilizers were bought and lime were bought as such, the farmer could save about three-fourths of the cost of lime in neutral fertilizers, or he could get three times as much lime for the same money. It, therefore, appears that buying high analysis acid fertilizers and lime is more economical than buying lower analysis neutral fertilizers.

Table 7.—THE EFFECT OF SOURCES OF NITROGEN ON THE LIME CONTENT OF THE SOIL.

Material	Per cent nitrogen	Gain or loss of lime for		
		1 pound of nitrogen	20 Pounds of nitrogen	100 Pounds of fertilizer
		Pounds	Pounds	Pounds
		Inorganic sources of nitrogen		
Nitrate of soda..............	16.	0.70 gain	14 gain	11 gain
Sulphate of ammonia.........	20.5	6.42 loss	128 loss	132 loss
Ammo-phos.................	11.0	6.07 loss	121 loss	67 loss
Anhydrous ammonia	82.2	2.87 loss	57 loss	236 loss
Calcium nitrate..............	15.0	0.28 gain	6 gain	4 gain
Calnitro....................	16.0	0.04 loss	1 loss	1 loss
Calnitro....................	20.0	1.07 loss	21 loss	25 loss
Crude nitrogen solution.......	44.0	2.28 loss	26 loss	100 loss
Potassium nitrate............	13.0	0.70 gain	14 gain	9 gain
Urea-ammonia liquor.........	45.5	2.87 loss	57 loss	131 loss
		Manufactured organic sources of nitrogen		
Cyanamid...................	22.0	1.78 gain	36 gain	39 gain
Urea......................	46.6	2.87 loss	57 loss	134 loss
Urea-ammonia liquor.........	45.5	2.87 loss	57 loss	131 loss
		Natural organic sources of nitrogen		
Cottonseed meal.............	6.7	2.47 loss	49 loss	17 loss

Data are presented on page 284 which show that there is some question about the use of dolomite to neutralize acid fertilizers. Additional research may reveal that acid fertilizers used on limed soils are more efficient than fertilizers neutralized with dolomite.

SUMMARY AND CONCLUSIONS

The data on methods for determining the effect of fertilizers on the lime content of the soil were reviewed and the following conclusions were drawn:

1. Nitrate of soda, which has soda equal to 3.57 pounds of lime for each pound of nitrogen present, maintains the lime content of the soil, and increases it slightly but not significantly. It is doubtful if fertilizers less basic than nitrate of soda should be used on acid soils without the use of lime.
2. The official method for determining the effect of fertilizers on the lime content of the soil does not require sufficient lime to keep soils from becoming more acid.
3. The addition of lime to correct the acidity produced by fertilizers does not offset the differences in the effect of fertilizers on the potash supply of the soil.
4. The cost of dolomitic limestone to the farmer is about $4.00 per ton when bought as such; when high analysis acid fertilizers are diluted with lime, it costs about $15.00 per ton.
5. High analysis acid fertilizers and lime can be bought for less than neutral fertilizers, which are made by diluting acid fertilizers with lime.

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(6)

The Use of Legumes to Supply Nitrogen;
The Uncertainty of Green
Manure Crops

*Grow crops for animals to eat; turn under crop residues
and animal manures.*

The following cropping regions in the United States require the
application of nitrogen in commercial fertilizers or the use of legumes
in rotation for economical crop production:

1. Cotton belt
2. Humid sub-tropical crop belt
3. Middle Atlantic trucking region
4. Corn and winter wheat belt
5. Corn belt
6. Hay and dairy region
7. Pacific sub-tropical crops region
8. Columbian plateau wheat region, and
9. Irrigated crops region.

The cropping regions of the United States (6)[1] are shown in Figure 1.

The spring and hard winter wheat regions use little nitrogen at the
present time; however, there are indications that nitrogen will even-
tually be required in these regions. The nitrogen which is applied to
crops in the cotton belt, humid sub-tropical crop belt, and the Middle
Atlantic trucking region is primarily commercial nitrogen and crop
residues. The nitrogen which is supplied to crops in the corn and
winter wheat belt, the corn belt, and the hay and dairy region is
primarily crop residues, leguminous green manure crops, and stable
manure much of the nitrogen of which comes from leguminous hay
crops. In the regions where most of the nitrogen is derived from

[1] Numbers in parenthesis refer to the source of information, page 155.
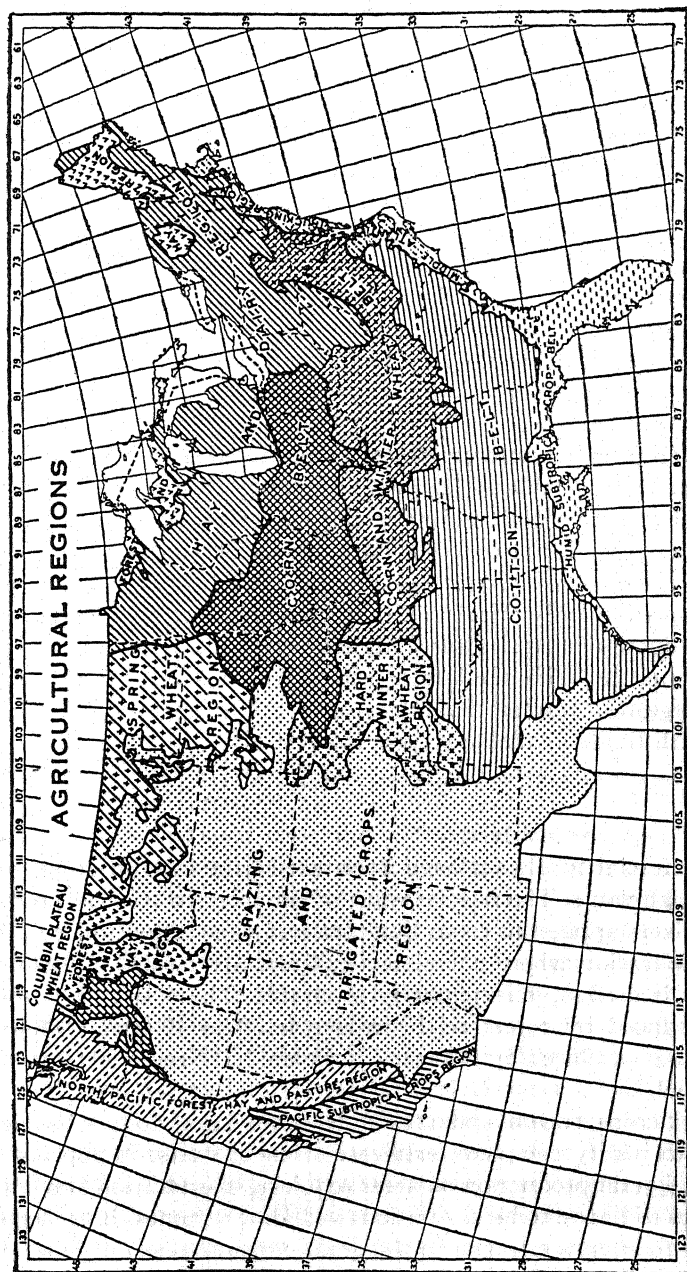
FIG. 1.—The cropping regions of the United States (6).

green manure crops and stable manure, these practices have proven profitable, and the use of commercial nitrogen has received little attention by experiment stations and farmers.

The climate in regions where most of the nitrogen comes from green manure crops and stable manure is such that the effect of these treatments lasts for several years. The cotton belt, as well as all other sections of the country, depended largely upon leguminous green manure crops and stable manure for nitrogen before 1900. The climate and soils are such that a large part of the nitrogen in summer leguminous green manure crops is lost before the following year; consequently, summer leguminous green manure crops never gained widespread use; also, the successful use of green manure crops is dependent upon the presence of a good supply of phosphorus in the soil, which was not generally present.

Winter green manure crops were experimented with in the Southeast prior to 1900. Winter legumes are planted in the fall and turned under in the spring before summer crops are planted, and the number of summer crops is not reduced. Regardless of the enthusiasm of educators for the use of winter legume green manure crops, the practice was accepted by only a few, and they used only a small acreage before the introduction of Agricultural Adjustment Administration payments for the practice. With the introduction of payments for the growth of winter legumes, farmers have increased the acreage of these crops. Even with funds available to pay most of the cash costs of planting and plowing under winter legumes, many farmers have failed to plant them, which indicates that they put a smaller value on winter legumes than on the labor involved.

Commercial fertilizers have been used primarily on crops which have a high value. The normal value of the increase in yield produced by fertilizers applied to crops like corn and oats is too low to justify their application where complete fertilizers are needed. Where only nitrogen is needed, it is generally profitable. The cost of a bushel of corn produced by commercial nitrogen is 30 to 40 cents; while the cost of that produced by the usual complete fertilizer is $0.60 to $1.00 per bushel.

Truck crops, cotton, and a few other crops have produced sufficient income to justify complete fertilizers on most years. It appears that successful grain production on areas requiring the addition of complete fertilizers will have to be in rotations including legumes. If the legumes are able to supply nitrogen to the grain crops, the cost of lime, phosphate and potash may be charged to both the legume and the grain

crop. The possibility of a successful rotation with grain crops appears to be much greater where legumes are utilized by animals than where they are used solely for green manuring; for in the latter case, the grain crop would of necessity have to carry the total cost of the fertilizer.

The rotation experiments conducted on the Morrow (Illinois) plots (11) had been going for 52 years when the data reported in Table 1

Table 1.—THE EFFECT OF SOIL TREATMENT ON CROP YIELDS ON THE MORROW PLOTS.

	Plot 3 Corn continuously		Plot 4 Corn, oats		Plot 5 Corn, oats, hay	
	No treat-ment	MLP[1]	No treat-ment	MLP	No treat-ment	MLP
	1888-1903					
Corn, bu. per acre....	39.7	.....	41.0	....	48.0	....
Oat, bu. per acre.....	.....	.....	44.0	....	47.6	....
Hay, tons per acre....	.....	.....	....	....	2.03	....
Profit[2]...............	$3.36	.....	$0.69	....	$4.77	....
	1904-1926, clover catch crop					
Corn, bu. per acre....	25.1	40.5	35.6	59.2	50.0	66.6
Oat, bu. per acre.....	.....	.....	34.0	58.1	45.1	62.7
Hay, tons per acre ...	.....	.....	....	....	1.39	2.40
Profit...............	−$6.33	−$1.95	−$2.89	$3.81	$2.09	$6.40

[1]M=manure, L=lime, P=phosphorus.
[2]Corn $0.75, and oats $0.45 per bu., hay $15.00 per ton, interest, labor, etc. calculated.

were published. The corn, oats, and hay were removed. The plots were divided in 1904, and manure, lime, and phosphate were added to half of each plot. Without the use of legumes after oats, (1888-1903) the yield of corn when grown continuously was practically equal to that in a rotation of corn and oats. Due to the fact that oats were less profitable than corn, the corn-oats rotation produced $2.67 less profit per acre than continuous corn. The yield of continuous corn declined from 40 bushels in 1888-1903 to 25 bushels in 1904-1926. In the corn, oats, hay rotation without treatment, $1.41 more profit was made during the 1888-1903 period than with continuous corn.

When legumes were used as a catch crop after oats, 1904-1926, $3.44 less money was lost in the corn-oats-legume catch crop rotation than with continuous corn. With the application of manure, lime, and phosphate, the rotation was $5.76 per acre more profitable than continuous corn. The yields of corn and oats in the corn-oats-hay rotation

without treatment were maintained over the 52 year period; however, the yield of hay was reduced sharply in the last period. The application of manure, lime, and phosphate during the 1904-1926 period increased the yield of corn 17 bushels, oats 18 bushels, and hay 1 ton.

Turning under 3,812 pounds of air-dry vetch per acre in New Jersey increased the 5-year average yield of corn 8.2 bushels of grain and 658 pounds of stover, or a total 1,132 pounds of corn and stover (26). The increase in yield of corn and stover was 30% of the air-dry weight of vetch. The feeding value of the vetch was much greater than that of the increase in yield of corn produced by turning vetch under.

That the growth of vetch is dependent upon the use of superphosphate is shown by the following data (30) from Alabama:

Treatment	Test 1 (7 years)	Test 2 (7 years)	Test 3 (9 years)	Average (23 crops)
	Yield of green vetch—pounds per acre			
None......................	2,734	723	964	1,473
400 lbs. superphosphate.......	8,092	4,425	5,254	5,923

The data show that vetch made very little growth without phosphate. The cost of 400 pounds of superphosphate per acre, including labor and interest, is about $5.00, most of which must be added to the cost of vetch seed and labor to arrive at the cost of growing vetch to supply nitrogen.

The effect of phosphate on the response of cotton to vetch is illustrated by data (30) from Alabama:

Treatment	Average yield of seed cotton, lbs. per acre			
	1896-1905	1906-1915	1920-1929	1930-1935
Cotton continuously, no nitrogen...	803	573	349	555
Cotton, vetch in winter..........	813	678	756	1,229

Cotton received 160 pounds of superphosphate and 160 pounds of kainit each year until 1920. Vetch had practically no effect on the yield of cotton for the first 20 years when only 160 pounds of superphosphate per acre was applied to the cotton, and none to the vetch. Beginning with the fall of 1921, 400 pounds of superphosphate was applied to the vetch each year, after which the yield of cotton on the vetch-treated plots was more than double the yield without vetch.

The average yield of vetch in 1926-'27-'29 with phosphate applied in the fall was 9,570 pounds of green material per acre.

Long-time tests, the treatments of which have produced big differences in crop yields, should be interpreted carefully. Where large differences in the growth of cotton or other summer crops are produced by soil treatment, plots on which the smaller growth is obtained are more subject to erosion than those producing larger crops. The most serious effect of erosion is probably the loss of organic matter containing nitrogen. **Where farmers are attempting to maintain good yields, soil treatments which have maintained approximately equal yields in long-time tests are a more valuable source of information than treatments which have produced large differences in crop production and soil fertility. Both are valuable.**

The Alabama Agricultural Experiment Station has obtained unusually good results (30) from the use of winter legumes (Table 2).

Table 2.—THE RESPONSE OF CORN AND COTTON TO VETCH
AND COMMERCIAL NITROGEN.

Sub-station	Increase in yield per acre				Yield of vetch green wt. per acre, after	
	With 36 lb. N.		With vetch			
	Seed cotton lbs.	Corn bus.	Seed cotton lbs.	Corn bus.	Cotton lbs.	Corn lbs.
Sand Mountain...	894	29	1,230	25	9,471	4,898
Tennessee Valley.	235	7	221	8	8,628	7,511
Wiregrass........	562	14	432	14	4,724	5,824
Average.........	564	17	628	16	7,609	6,111

The soils received 600 pounds of 0-10-4 fertilizer per acre each year or a total of 120 pounds of phosphate and 48 pounds of potash for the 2-year rotation. Where nitrogen fertilizer is used for corn and cotton production in a 2-year rotation, only 48 pounds of phosphate and 24 pounds of potash is recommended by the Alabama Experiment Station for cotton, and nitrogen only (29) for corn. Evidently the 2-year rotation received 72 pounds of phosphate and 24 pounds of potash per acre more than is recommended where nitrogen fertilizer is used. As was pointed out above, success with vetch and other winter legumes depends to a large extent upon the use of phosphate. If the extra phosphate and potash were necessary with vetch and not necessary with the commercial nitrogen, its cost should be added to the cost of

growing vetch. The cost of the extra phosphate and potash, including interest and labor, is about $5.50.

As the data stand, the commercial nitrogen (225 pounds of nitrate of soda) (a) was equal to vetch at the Tennessee Valley Station, (b) was superior to vetch by 130 pounds of seed cotton valued[1] at $6.50 at the Wiregrass Station, and (c) produced 336 pounds less cotton and 4 bushels more corn at the Sand Mountain Station, which is $13.80 ($16.80 — $3.00) less profitable than vetch. If the cost of the extra phosphate and potash should be charged to the vetch, the commercial nitrogen made:

1. $5.50 more profit at the Tennessee Valley Station.
2. $12.00 more profit at the Wiregrass Station.
3. $8.30 less profit at the Sand Mountain Station.
If the vetch were required to make $2.00 profit per $1.00 invested in the extra phosphate and potash, commercial nitrogen made:
1. $16.50 more profit at the Tennessee Valley Station.
2. $23.00 more profit at the Wiregrass Station.
3. $2.70 more profit at the Sand Mountain Station.
It does not appear unreasonable to require vetch to make a profit of $2.00 per $1.00 invested in the extra phosphate and potash.

Vetch or Austrian winter peas have produced increases in yield of cotton which are about equal to that produced by 150 pounds of nitrate of soda (9) in tests on upland and valley soils in Mississippi:

Treatment	Yield of seed cotton—pounds per acre						
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
No nitrogen...........	598	1,105	857	.....	.....	...	.....
150 pounds of nitrate of soda.............	991	.....	.....	1,270	2,085	397	1,254
225 pounds of nitrate of soda.............	...	1,281	1,021	.....	.....	...	.....
Austrian winter peas...	818	1,199	916	1,280	2,144	385	1,182
Hairy vetch...........	...	.....	.....	1,292	2,095	356	1,251

The cost of 150 pounds of nitrate of soda is approximately equal to the seed cost of vetch or Austrian winter peas. The labor involved is much greater for the green manure crops. Thirty-two pounds of phosphate and 16 pounds of potash were used for the cotton in the tests where 150 pounds of nitrate of soda was applied. Where 225

[1]Seed cotton was valued at 5 cents per pound and corn at $0.75 per bushel.

pounds of nitrate of soda was used, the cotton received 48 pounds of
phosphate and 24 pounds of potash.

**Where at least 2,000 pounds per acre of air-dry vetch or Austrian
winter peas was turned under in Georgia, 1,044 pounds of seed cotton
was produced**; where 100 pounds of nitrate of soda was applied, 951
pounds of seed cotton was produced; and where 200 pounds of nitrate
of soda was applied, 1,154 pounds of seed cotton per acre was produced
(14). The data are an average for 8 years. Superphosphate was used
at the rate of 600 pounds, and potash at 64 pounds per acre. The 2,000
pounds of winter cover crop was equal to approximately 150 pounds
of nitrate of soda. Twice as much phosphate and potash was used
as is normally recommended where nitrogen fertilizer is applied to
cotton.

**Planting vetch every other year in a two-year rotation of cotton-
vetch-corn proved to be a good system as an average of data on three
soils in Alabama (30) as shown in Table 3.** The vetch crop was equal
to 36 pounds of nitrogen for corn, and it had a residual effect which
produced 213 pounds of seed cotton per acre. The application of 36
pounds of nitrogen produced 317 pounds more seed cotton than the
residual effect of vetch. The application of 36 pounds of nitrogen to
cotton following corn which had vetch increased the yield of cotton
460 pounds and the yield of corn after vetch 6 bushels. The use of

Table 3.—THE USE OF VETCH AND NITRATE OF SODA IN A TWO YEAR ROTATION.

Treatment[1]	Yield per acre		
	Vetch[2]	Seed cotton	Corn
	Pounds	Pounds	Bushels
Cotton-corn no nitrogen....................	.....	795	16
Cotton-corn 36 pounds nitrogen to each.......	.....	1,325	32
Cotton-vetch-corn........................	7,810	1,008	34
Cotton-vetch-corn 36 pounds nitrogen to cotton.	10,475	1,468	40

[1] All plots received 600 pounds of 0-10-4 per acre per year.
[2] Green weight.

commercial nitrogen on cotton increased the yield of vetch from 7,810
to 10,475 pounds per acre, which is attributed to the affect of the soda
in nitrate of soda. It should be pointed out that the cotton received 12
pounds more phosphate than is generally recommended for cotton, and
the corn received 600 pounds 0-10-4, which is not generally recom-
mended for corn in a rotation with fertilized cotton. The additional
fertilizer cost approximately $5.50.

Vetch every other year and commercial nitrogen every other year made 143 pounds of seed cotton and 8 bushels of corn more than 36 pounds of commercial nitrogen every year, which has a value of $13.15. If the cost of the extra fertilizer ($5.50) is subtracted, there is a profit of $8.65 in favor of vetch every other year as compared to commercial nitrogen every year. The additional profit is less than is normally obtained on an investment of $5.50 in fertilizer.

The application of 600 pounds of superphosphate (2/3 to vetch and 1/3 to the following crop) in Alabama (30) increased the yield of vetch 4,933 pounds of green weight per acre, which increased the yield of corn 5 bushels, and seed cotton 195 pounds per acre. The increase cost $7.50 and is valued at about $13.50, which leaves a profit of $6.00. The data are reported in Table 4. The application of 100

Table 4.—THE RESPONSE OF COTTON AND CORN TO VETCH GREEN MANURE.

Treatment	Yield per acre[1]		
	Seed cotton	Vetch	Corn[2]
	Pounds	Pounds	Bushels
None.....................................	751	4,288	26
600 lbs. superphosphate....................	946	9,221	31
600 lbs. superphosphate, and 75 lbs. muriate of potash.................................	1,047	9,959	32
600 lbs. superphosphate, 75 lbs. muriate of potash, and 100 lbs. nitrate of soda to cotton and corn................................	1,218	10,612	34

[1]Six-year average yield on Sand Mountain, Tennessee Valley, and Wiregrass Sub-Stations, and on Alexandria, Aliceville, Brewton, Monroeville, and Prattville Experiment Fields.
[2]The corn yields are low because soybeans were interplanted with corn five years out of the 6-year period.

pounds of nitrate of soda to cotton, costing about $1.80, in addition to vetch made a profit of $6.75.

The application of phosphate and potash to winter legumes in the fall is not sufficient (27) on soils requiring these fertilizers for cotton production (Louisiana) (Table 5). The application of 300 pounds of superphosphate (16%) and 60 pounds of muriate of potash to vetch or Austrian winter peas rather than to cotton increased the yield of these crops slightly more than one ton per acre. However, with the smaller yields of green manure crops, spring application of the phosphate and potash to cotton produced 119 pounds more seed cotton where vetch was used, and 58 pounds more where Austrian winter peas

were used than did fall applications of these fertilizers. Fall application of superphosphate to vetch and Austrian winter peas was satisfactory for cotton production on limed soil. Vetch or Austrian winter peas was superior to 240 pounds of nitrate of soda in this test.

Table 5.—TIME OF APPLICATION OF SUPERPHOSPHATE IN A VETCH-COTTON PROGRAM.

Treatment for cotton	Time of application	10-year average yield per acre	
		Cover crop	Seed cotton
		Tons	Pounds
240 lbs. nitrate of soda..............	Spring	. . .	1,090
No nitrogen.........................	Spring	. . .	716
Hairy vetch.........................	Spring	7.0	1,159
Hairy vetch.........................	Fall	8.1	1,040
Hairy vetch—limed..................	Fall	8.2	1,163
Hairy vetch—limed..................	Fall[1]	8.4	1,181
Winter peas.........................	Spring	6.1	1,147
Winter peas.........................	Fall	7.2	1,089
Winter peas—limed.................	Fall	7.9	1,150

[1] Potash in spring.
300 lbs. superphosphate, 60 lbs. muriate of potash applied per acre.

Higher yields of cotton following vetch green manure were made in Mississippi (5) where 0-8-4 fertilizer was applied to cotton rather than to vetch, even though its application to vetch increased the yield of green manure about 50%. The yield of vetch green manure was 4,216 and 5,736, and 3,446 and 5,067 pounds per acre where 500 pounds of 0-8-4 was applied to cotton and to vetch preceding cotton, respectively, in two tests. The increase in yield was 55, and 63 pounds of seed cotton per acre for the two respective tests in favor of applying the 0-8-4 directly to the cotton, even though more green manure was made where it was applied to the vetch.

The effect of applying fertilizer to vetch as compared to application to cotton is shown by data reported in Table 4, page 175. Where the vetch was cut for hay the 5-year average yield was 5,678 and 3,886 pounds of green vetch per acre, and 850 and 1,046 pounds of seed cotton, where the fertilizers were applied to the vetch or to the following cotton crop, respectively. Where vetch was turned under for green manure the corresponding yields were 6,262, and 4,379 pounds of vetch, and 1,141, and 1,232 pounds of seed cotton. These data show that higher yields of cotton are made after lower yields of vetch where the fertilizer is applied directly to the cotton, rather than where it is applied to the vetch.

Farmers' experience with the use of winter legumes (20) have been accumulated (Table 6). On the basis of 100 pounds of lint cotton being equal to 286 pounds of seed cotton, the average increase in yield produced by winter legumes is 51 pounds of seed cotton per acre less than was obtained for 30 pounds of nitrogen from nitrate of soda in 222 experiments conducted by the Alabama Agricultural Experiment Station. The 51 pounds of seed cotton is worth $2.55 at 5 cents per pound. Adding the average cost of the fertilizer applied to the legumes (0.50) to the difference in value gives 30 pounds of nitrogen in nitrate of soda, an advantage of $3.00 per acre, without taking into con-

Table 6.—FARMERS' EXPERIENCE WITH WINTER GREEN MANURE CROPS.

Cotton—1877 acres[1]			Corn—4,145 acres[2]		
Increase in yield lint cotton		Average	Increase in yield per acre		Average
Group	Average		Group	Average	
Pounds per acre		Percent	Bushels	Bushels	Percent
Decreases.........	−176	3	Decreases........	−7	1
No increase........	0	15	No increase.......	0	9
1 to 50...........	33	10	1 to 5...........	5	10
51 to 100.........	86	26	5½ to 10.........	9	22
101 to 150........	135	25	10½ to 15........	15	26
151 to 200........	186	12	15½ to 20........	19	13
201 to 250........	233	6	20½ to 25........	24	10
Over 250.........	321	3	25½ to 30........	29	3
			Over 30.........	38	5
Weighted average...	100		Weighted average..	14	

[1]The fertilizer cost $0.50 per acre.   [2]The fertilizer cost $0.81 per acre.

sideration the cost of vetch and nitrate of soda. On the basis of farmers' experience, vetch green manure crops appear to be less profitable than nitrate of soda on the average. For corn production, winter legumes increased the yield less than 10 bushels on 42% of the acreage, and on 31% of the acreage the increase was more than 15 bushels per acre. The use of 200 pounds of nitrate of soda usually increases the average yield of corn about 12 bushels per acre.

Soils which have an abundance of lime, phosphorus, potash, and other elements necessary for the growth of winter legumes may give more profitable response to winter legumes than to commercial nitrogen. The (7-year average) data from one test in the Mississippi Delta (21) are illustrative (Table 7). All of the legumes used in this test increased the yield of seed cotton more than did nitrate of soda. Vetch

produced about 50% more increase in yield of cotton than did any other legume, for which there is no explanation. Since in other tests the increase in yield has been determined largely by the quantity of nitrogen produced, the superiority of hairy vetch over the other legumes in this test would not be expected to hold up on other soils unless there is a difference in the amount of nitrogen in the different cover crops.

Table 7.—THE RESPONSE OF COTTON TO GREEN MANURE CROPS ON A FERTILE SOIL.

Treatment	Yield of cover crop, dry weight per acre	Nitrogen	Increase in yield of seed cotton per acre
	Pounds	Pounds	Pounds
Austrian winter peas..............	2,124	61	494
Hairy vetch......................	2,694	84	727
Sweet clover.....................	1,913	54	420
Bur clover.......................	3,717	111	494
30 pounds commercial nitrogen......	.....	...	363
Yield without nitrogen.............	.....	...	1,023

Vetch and Austrian winter peas produced twice as much increase in yield of seed cotton as 150 pounds of nitrate of soda on fertile delta land (32) in Louisiana which produced 1,038 pounds of seed cotton without fertilizer:

Treatment	6-year average—yield per acre
	Pounds
None...........................	1,038
150 pounds of nitrate of soda.....	1,467
Austrian winter peas................	1,817
Hairy vetch......................	1,966

The unusually good response of cotton to winter legumes is attributed to the high fertility of the soil.

The effect of soil fertility upon the relative value of winter legumes and nitrate of soda is shown by the data (10) in Table 8 from Louisiana on Olivier silt loam soil. Greater yields were obtained from vetch or Austrian winter peas than from 36 pounds of nitrogen in nitrate of soda on the fertile soil which produced an average of 1,177 pounds of seed cotton per acre without nitrogen; on the soil producing 775 pounds of seed cotton without nitrogen, 36 pounds of nitrogen in nitrate of

soda was slightly superior to vetch and probably significantly superior to Austrian winter peas. An estimated 41 pounds of nitrogen in sweet clover produced nearly as much seed cotton as 36 pounds of nitrogen in nitrate of soda on the very fertile soil; on the less fertile soil 105 pounds of nitrogen in vetch produced slightly less seed cotton than 36 pounds of nitrogen in nitrate of soda; and 79 pounds of nitrogen in Austrian winter peas was inferior to 36 pounds in nitrate of soda.

Table 8.—THE EFFECT OF SOIL FERTILITY ON THE RESPONSE OF COTTON TO GREEN MANURE CROPS.

Soil treatment	Very fertile soil		Fertile soil	
	Nitrogen in cover crop[1]	4-year average yield seed cotton per acre	Nitrogen in cover crop	4-year average yield seed cotton per acre
	Pounds	Pounds	Pounds	Pounds
No nitrogen...........	..	1,177	...	775
Vetch.................	70	1,750	105	1,376
Sweet clover..........	41	1,589	...	.....
Austrian winter peas...	69	1,747	79	1,322
Nitrate of soda........	36	1,646	36	1,418

[1]Estimates based upon yield and on nitrogen content of legumes on the less fertile soil.

Fertile soils have sufficient nutrients to grow good crops of legumes early and to promote rapid decay, from which a good supply of nitrogen is made available for the following crop. On poor soils, the rate of growth of legumes is slow, and the rate of decomposition may be too slow to give sufficient nitrogen to the following crop in the early stages of growth.

Other data on winter legumes in the Mississippi Delta (21) gave the following increases in yield of seed cotton per acre:

Treatment	Field				
	1	2	3	4	5
	Increase in yield, lbs. seed cotton per acre				
30 lbs. of nitrogen..........	330	506	217	354	341
Hairy vetch................	533	487	193	383	341
Austrian winter peas........	310	78	204	333	292
Bur clover................	−17	296	...	...	...

Except in test No. 1, which was a 1-year test, there was little difference between the increase in yield of seed cotton produced by winter legumes and that produced by 30 pounds of commercial nitrogen.

The importance of planting date of cotton as influenced by turning a vetch crop under 10 days before planting is illustrated by data (18, 30) from Alabama (Table 9). Turning under 4,317 pounds of

Table 9.—THE EFFECT OF DATE OF PLOWING VETCH UNDER ON THE YIELD OF CORN AND COTTON.

Date row crop planted		Date vetch turned	14-year average—yield per acre	
			Seed cotton	Corn
			Pounds	Bushels
April 5	no legumes............	....	612	7
April 5	200 lbs. nitrate of soda....	....	.....	19
April 5	300 lbs. nitrate of soda....	....	1,323	..
April 5	4,317 lbs. vetch.........	March 25.....	1,248	23
April 15	300 lbs. nitrate of soda....	....	.....	28
April 15	7,506 lbs. vetch.........	April 5.......	1,213	29
April 25	300 lbs. nitrate of soda....	....	1,264	..
April 25	400 lbs. nitrate of soda....	....	.....	29
April 25	9,327 lbs. vetch..........	April 15......	1,275	33

green vetch in time to plant cotton April 5 was just as effective as 7,506, or 9,327 pounds 10 and 20 days later, respectively. For the April 5 planting of cotton, 300 pounds of nitrate of soda made 75 pounds more seed cotton than vetch which is worth $3.75 at 5 cents per pound. The cotton and vetch received 600 pounds of superphosphate and 75 pounds of muriate of potash during the early years of the test at least, which is 300 pounds more of superphosphate and more potash than is generally recommended for cotton. The value of the additional phosphate at $25.00 per ton is $3.75.

Rye had little influence on the yield of corn in three tests conducted in Mississippi (9) as shown by data reported in Table 10. Rye did not

Table 10.—THE RESPONSE OF CORN TO NITRATE OF SODA, AUSTRIAN WINTER PEAS, AND RYE.

Treatment	5-year average yield—bushels per acre		
	Test 1	Test 2	Test 3
30 lbs. nitrogen......................	34	36	21
Austrian winter peas.................	24	42	20
Rye.................................	17	23	13
30 lbs. nitrogen and rye..............	30	33	21
Check................................	19	28	15

increase the yield on any soil. Nitrate of soda containing 30 pounds of nitrogen was superior to Austrian winter peas in one test, and inferior in one test.

The success of a winter legume program in the Southeast, as has been pointed out above, is shown by data (10) from Louisiana to be dependent upon the fertilizer used (Table 11). The use of basic slag

Table 11.—THE RESPONSE OF WINTER LEGUMES TO FERTILIZERS AND INOCULATION.

Treatment	Average yield of vetch or Austrian winter peas (13 soils)	Increase due to fertilizer	
		Vetch or peas	Nitrogen
	Tons	Tons	Pounds[2]
No inoculation..........................	1.0	...	..
Inoculation.............................	2.2	..	..
Inoculation plus 225 # superphosphate.....	4.0	1.8	22
Inoculation plus 500 # basic slag..........	3.9	1.7	20
Inocluation plus 1000 # lime...............	2.9[1]	0.7	8
Inocluation plus superphosphate and lime..	5.0[1]	2.8	34
Inoculation plus superphosphate and 50 pounds of muriate of potash...........	3.8	1.6	19

[1] 9 soils.   [2] Estimated on basis of 12 lbs. nitrogen per ton.

or superphosphate increased the yield of vetch and Austrian winter peas. The higher yields of these crops contained more nitrogen. On the basis of data represented above it is doubtful if the nitrogen in legumes is worth over 3 cents per pound; if it is not worth over 3 cents per pound, these data suggest that winter legumes will not compete with commercial nitrogen on the 13 soils, and that the increases in the nitrogen produced by the fertilizers were not profitable.

The planting date of corn may be of more importance than a winter legume cover crop. Unpublished data from Mississippi show that early-planted corn without vetch produced higher yields than corn planted after vetch had made a fair growth:

Treatment	Planting date	Year						
		1922	1923	1924	1925	1926	1927	Average
		Yield, bushels per acre						
None.........	Early........	38	58	28	30	33	34	37
Vetch........	Later........	34	28	0	0	50	18	22 .

Two corn failures were obtained with late-planted corn after vetch. When corn with both treatments was planted on an intermediate planting date, the following yields were obtained:

Treatment	Yield—bushels per acre						
	1928	1929	1930	1931	1932	1933	Average
None.........	32	27	22	38	31	45	33
Vetch.........	56	40	21	40	32	45	39

With both treatments planted on the same date, vetch increased the yield of corn 6 bushels per acre.

The effect of crops on soil erosion has received considerable attention during the past few years. Erosion is prevented to a large extent by the tops of plants, or cover which breaks the force of the falling rain drops. Complete cover of the soil by growing crops reduces erosion to a minimum. It has been shown that soil treatment which increases the growth of plants reduces erosion. Evidently, the application of nitrogen from any source, phosphorus, potash, lime, or any element which increases the yield of crops will reduce erosion. The season of the year at which the hardest rains come is usually when most soil is lost by erosion. The hardest rains come in the Southeast during June, July, and August. Soil treatments which increase the size of plants during these months will reduce erosion.

The method of planting winter legumes determines whether they decrease erosion or not. It is recognized that freshly plowed land erodes more easily than unplowed land, where the leaves, stalks, and grass from the previous crop are on the surface. Crop residues break the fall of drops of rain and form small dams, which reduce run off and erosion. During long periods when land is not plowed, soil becomes granular, due to wetting and drying and the action of roots, which promotes percolation of water through the soil and reduces run-off and erosion.

When land is freshly plowed, rain beats up the soil and brings clay into suspension, which may settle out in a thin layer on top of the soil, through which water goes very slowly. Due to the formation of these clay layers, freshly plowed soil may hold water in the furrows for several days after a rain, while furrows in unplowed soil with crop residues on top rarely hold water for any length of time. The reason for plowed soil's being more erosive is apparent. Unplowed soil, which

has a natural cover of weeds and grass and crop residues, does not erode. Many farmers lay by crops early, which promotes the growth of a protective cover of weeds and grass.

From an erosion standpoint, plowing land in the fall for planting cover crops increases erosion until the land has as good cover as the unplowed land, which is probably the latter part of March or the first part of April in the Southeast (24). Where winter cover crops are planted with a drill on unplowed land, or are sown at the last cultivation of the summer crop as bur clover is sown, or are sown on top of unplowed land without covering, erosion is not increased. Winter crops like bur clover, which are planted at the last cultivation of summer crops, are more desirable from the standpoint of erosion control than crops which require soil preparation.

The economic importance of the loss of 56 tons of soil by erosion has been calculated (28), assuming values for the nitrogen, phosphorus, and potash equal to that in nitrate of soda, superphosphate, and muriate of potash. The value of 56 tons of soil was calculated (28) as follows:

Nitrogen	$ 8.75
Phosphorus	12.00
Potash	38.40
Total	$59.15

from which the value of an acre to a depth of 6 2/3 inches, which contains 1000 tons of soil, was calculated by the author as follows:

Nitrogen	$156.25
Phosphorus	214.29
Potash	685.71
Total	$1,056.25

These values appear to be out of line with values of land, which may be due to the availability of nitrogen, phosphorus, and potash in soils being very low as compared to that in fertilizers. Since in many cases the soil left after eroding away the top soil contains as much or more phosphorus and potash as the soil which eroded away, the harmful effect of erosion is probably due largely to the loss of organic matter containing nitrogen. Under sods the organic matter can be restored by legumes and grasses, and other vegetation.

The productivity of many sandy soils with a sandy topsoil underlaid with sandy clay subsoils has been temporarily reduced to a low level by erosion. These soils may be brought back to a high produc-

tivity level by giving nature a chance to revegetate them and restore the organic matter lost by erosion, or the productivity may be restored more rapidly by growing non-cultivated crops (Fig. 2). Since the sandy clay subsoil, which becomes the topsoil after erosion has taken place, contains more of all plant nutrients except nitrogen than the uneroded topsoil, when these soils are eroded and good practices are followed they become more productive than if no erosion had taken place. Examples of soils with high productivity which were once thought to have been ruined by erosion are well known to most observers.

FIG. 2.—Lespedeza sericea restored the productivity of badly eroded land for corn production, and produced hay at the same time (7).

The productivity of soils with sandy loam topsoils underlaid with heavy clay subsoils for row crops has been decreased to very low levels, which may be almost permanent. These soils were uncertain row crop soils when brought into cultivation; they were best suited for grazing and forests; fortunately, they are still suited for these land uses. If given a chance, nature will restore a forest cover.

The physical features of many soils on steep slopes have been impaired by erosion for row crops for which they were not suited; fortunately, they will still produce good forests if nature is given a chance to restore a forest cover. Abandoned houses, sedge fields and

pine thickets suggest that the unsuitability of land for row crops has been recognized, and that more remunerative land or jobs have been sought, thereby giving nature a chance to restore the land to forests, for which it is suited.

The productivity of a large acreage of poorly drained heavy bottoms has been increased by sandy material from upland soils; that of a small acreage has been decreased by too much sandy material from uplands. Many bottoms which are productive at the present time were too poorly drained to be cultivated before sandy material was deposited on them.

All land was suited to the production of some commercial crop before it was brought into cultivation; most land is potentially capable of producing high yields of the same crop for which it was naturally suited before being brought into cultivation. Record yields of most crops have been produced in recent years, which is evidence of the fact that the soils have not lost their potential productivity.

The problem is to determine the crop for which land is potentially suited, after which the returns from the crop in question will determine the effort which may be applied to establish the crop. In the meantime nature will revegetate unused land, usually with the crop it had before it was brought into cultivation. In many cases old fields come back to almost pure stands of pines which are valuable, while, on nearby cut-over land, less valuable oaks predominate. Even for forests previous cultivation and abandonment of land on account of erosion may have an advantage over cut-over virgin land.

Where winter legumes are used, insects sometimes injure stands so much that crops have to be planted over. When the season is unfavorable, a crop may be lost after winter legumes, where a good crop would have been obtained without them. These losses must be accounted for in the evaluation of winter legumes.

The use of winter legumes for cotton production may result in later planting of cotton. Boll weevils are a greater hazard where cotton is planted late. Many experiment stations control boll weevils; most farmers do not control them. Early planting of cotton is desirable where boll weevils are present. Where the use of winter green manure crops results in later planting of cotton where boll weevils are not controlled, data obtained by experiment stations where boll weevils are controlled may have little value to farmers.

In the interpretation of the effects of fertilizers on the yield of winter legumes, it should be borne in mind that data presented above (pages 130 and 131) show that superphosphate applied to winter cover

crops will not take the place of superphosphate for cotton, except possibly where the lime content of the soil is maintained at a high level. In fact, the necessity of superphosphate or lime for cover crops indicates that cotton must have these fertilizers also. On soils on which cotton gives good response to superphosphate, phosphate is required for success with winter legumes. Where winter legumes require phosphate or lime for success, the cost of these fertilizers must be added to the other costs of the winter legume program, which makes the cost of the winter legume program higher than the cost of producing the same yield of crops using commercial nitrogen.

The 1940 cost per acre of using a winter green manure crop is estimated as follows:

Seed...	$ 3.00
Planting......................................	2.00
200 pounds of superphosphate....................	2.50
Applying fertilizer.............................	.50
Extra work in preparing land for following crop....	2.00
Total..	$10.00

The estimated prices will vary; however, additional charges must be made for management, and the risks involved in securing a stand of the following crop. On most soils the winter green manure crop will increase the yield of the following crop no more than will 75 to 100 pounds of ammonium nitrate costing $2.00 to $2.75.

The data on the use of winter legumes as a whole indicate that they are superior to commercial nitrogen for increasing the yield of the following crop on a few soils, and inferior on many soils. Decreases in yield of the following crop are sometimes obtained where winter legumes are used. The decreases are probably due to late planting and failure to get a stand after turning the legume under.

The success of winter legume green manure crops depends upon the soil. On heavy soils the seed bed for corn and cotton needs to be prepared in the fall and winter. These soils may be plowed wet in the fall and winter, and no injurious effect is produced because wetting and drying granulates them before spring. Where winter cover crops are planted on heavy soils, it may be too late to plant a crop before a seed bed can be prepared in the spring. The seed bed on sandy loam soil is normally prepared in the spring, and winter cover crops are much more satisfactory on sandy loam or similar soils than on heavier soils.

The question is often raised: How much nitrogen is necessary in the tops of a winter legume crop to be equal to one pound of nitrogen

in nitrate of soda? In Louisiana (10) on one soil of high fertility, it took about 3 pounds of nitrogen in vetch to be equal to one pound of nitrogen in nitrate of soda.

On very fertile soils, one pound of nitrogen in winter legumes sometimes appears to be about as good as one pound of nitrogen in nitrate of soda, but this occurrence is infrequent. Even though the relative value of winter legume and nitrate of soda nitrogen varies, it appears that under average conditions 2½ to 3 times as much winter legume nitrogen will be required to get the same increase in yield of crops as is obtained from a given amount of nitrogen in commercial sources.

Winter legumes contain approximately 12 pounds of nitrogen per ton of green material. The nitrogen in green manures is usually less than half as efficient as that in nitrate of soda. Nitrogen in ammonium nitrate costs about 8 cents per pound, normally. Nitrogen in green manures is probably not worth more than 3 cents per pound, based on data above from a soil which produced 775 pounds of seed cotton per acre without nitrogen. The value of nitrogen in green manure crops varies, but an average value of 3 cents per pound for that in winter green manures in the Southeast is probably a fair estimate. A value of 3 cents per pound of nitrogen or 36 cents per ton of green manure may be a fair estimate of their value as a green manure.

The fixation of one pound of nitrogen by nodule bacteria reduces the yield of the legume as compared to the yield where nitrogen is obtained from the soil (4). It was found that on a dry year when plant food production was low, the yield of soybeans was reduced about 50 pounds per acre for each pound of nitrogen fixed by nodule bacteria as compared to the yield obtained when the nitrogen came from the soil. The reduction in yield is probably greater when plant food production is lower, and in seasons (high rainfall) when an abundance of plant food is produced the reduction in yield is not noticeable. In good seasons the legume plant is able to manufacture sufficient food for both the nodule bacteria and the plant.

The yield of corn is generally limited by nitrogen or water. When corn is limited by nitrogen to a very low yield and sufficient moisture is present for a much higher yield, planting soybeans (or other legumes) in corn reduces the yield of corn little if any the first year. At the same time the nitrogen content of the soil is increased temporarily at least. Where the soil and climate are such that a significant quantity of the added nitrogen is retained for the next crop year, the yield of the following corn crop is increased.

The yield of corn was reduced 2 bushels per acre for each bushel of soybeans produced when interplanted with corn in various ways in Kentucky (25). The soil presumably had sufficient nitrogen for a good corn crop. With a 50-bushel corn yield in Tennessee without legumes (22), the production of one bushel of soybeans reduced the yield of corn one bushel. With a 39-bushel yield without legumes, the production of one bushel of cowpeas reduced the yield of corn 1½ bushels.

Growing soybeans in corn continuously had no significant effect

Table 12.—THE VALUE OF COWPEAS AND SOYBEANS IN CORN FOR COTTON AND OAT PRODUCTION.

Test number	1	2	3	4	Average	5	6	7	Average
Duration, years	6*	7	6*	13		6	6*	12*	
Legume	Increase in yield of corn—bushels per acre								
Cowpeas in drill......	−6	−6	−3	−5		−5	−5	−4	−4.9
Cowpeas in middle....	−3	−3	−3	−2		5	2	0	−0.6
Soybeans in drill.....	−10	−4	0	1		−7	−3	−5	−4.0
Velvet beans in drill..	−3	−1	...	...		−11	...	...	.....
Yield without legumes.	33	25	13	19		42	17	29	
	Increase in yield of seed cotton—lbs.					Increase in yield of oats—bus.			
Cowpeas in drill......	330	66	204	184	196	4	6	4	4.7
Cowpeas in middle....	182	19	1	32	59	4	4	3	3.7
Soybeans in drill.....	116	269	272	250	227	6	6	4	5.3
Velvet beans in drill..	70	305	...	...		2	..	...	...
Yield without legumes.	966	842	626	752		39	25	33	...

*One year less for cotton or oats.

on the yield of corn in four tests conducted in Mississippi (9). The Arkansas Agricultural Experiment Station conducted seven tests with different legumes in corn, and after each corn and legume crop, cotton or oats was grown to make use of the legume nitrogen added to the soil. When the legume is grown in competition with a crop of low acre value, like corn, and followed by cotton which has a high acre value, maximum increase in value of the crop following the legume is obtained. Part of the Arkansas data (19) are summarized in Table 12.

Cowpeas and soybeans in the drill reduced the yield of corn an average of 4.9 and 4.0 bushels per acre, respectively. The growth of cowpeas and soybeans in corn increased the yield of the following cotton crop 196 and 227 pounds of seed cotton per acre, respectively.

The value of the increase in yield of seed cotton is 3 times the value of the decrease in yield of corn.

Where no nitrogenous fertilizer is used on cotton which follows corn, these data indicate that the use of cowpeas or soybeans in the drill with corn is highly profitable. However, the cost of the cowpea or soybean seed plus the value of the 4 to 5 bushels of corn lost by growing them in the corn would have bought from 30 to 40 pounds of commercial nitrogen, which should have produced double the increase in yield of seed cotton produced by the cowpeas and soybeans.

The growth of cowpeas and soybeans in corn increased the yield of the following oat crop 4 to 5 bushels, but these increases are less valuable than the decrease in yield of corn. Cowpeas planted in the corn middles at lay-by time reduced the yield of corn slightly 4 times out of 7 and (doubtfully) increased it 2 times. They had no significant effect on the yield of cotton except in one test.

The value of summer legumes for increasing the yield of cotton was compared with 18 pounds of nitrogen (112 pounds of nitrate of soda) in Mississippi. The data (16)[1] for Otootan soybeans on Ruston soil are illustrative of the data obtained. The soybeans contained an average of 40 pounds of nitrogen per acre, and lacked 12 pounds of producing as much seed cotton as 18 pounds of nitrogen in nitrate of soda. Where the soybean stubble only was turned under, the yield of seed cotton was 52 pounds less than where nitrate of soda was used. Turning under approximately one ton of soybean hay increased the yield of seed cotton 40 pounds over the yield for stubble only. The soybeans were left on the land, which has been found more desirable for lespedeza and soybeans than fall plowing in Kentucky and Alabama, respectively. The nitrogen content of the soybean residue in the spring was 0.75%. Due to their low nitrogen content the legume residues left in the spring were probably only a little more valuable than non-legume crop residues. The cost of 112 pounds of nitrate of soda is approximately $2.00; the 1940 per acre cost of growing soybeans for green manure is estimated as follows:

Land rent	$3.00
Preparing land and planting	4.00
Seed	1.50
Fertilizer—200 lbs. superphosphate	2.50
Applying fertilizer	.50
Cultivation	2.00
Total	$13.50

[1] Also unpublished data.

The cost of growing summer annual legumes for supplying nitrogen to other crops is entirely too much to permit their use with the present prices of commercial nitrogen.

Soybeans containing an average of 69 pounds of nitrogen per acre per year was compared to 25 pounds of nitrogen in nitrate of soda for production of wheat and rye (8) at the New Jersey Agricultural Experiment Station and the results are reported in Table 13. The 25

Table 13.—THE VALUE OF SOYBEANS FOR GREEN MANURE.

	Wheat				Rye			
	No green manure		Green manure		No green manure		Green manure	
Period	No top-dress-ing	Top-dress-ing	No top-dress-ing	Top-dress-ing	No top-dress-ing	Top-dress-ing	No top-dress-ing	Top-dress-ing
	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels	Bushels
1909-1913.....	13	..	20	..	18	..	24	..
1914-1918.....	9	..	16	..	18	..	20	..
1919-1923.....	16	..	18	..	20	..	25	..
1924-1928.....	16	21[1]	18	24[1]	18	26[1]	19	25[1]
1929-1933.....	18	24	19	25	16	25	17	25
1934-1938.....	17	24	27	28	14	23	19	23
30-Yr. Av.....	15	..	20	..	17	..	21	..
14-Yr. Av.....	17	23	21	26	16	25	19	24

[1] 4-Year averages—top-dressing did not begin until 1925.

pounds of nitrogen in nitrate of soda made 1.6 bushels more wheat and 5.9 bushels more rye than 69 pounds of nitrogen in soybeans. The nitrate of soda cost about $3.00; the soybeans cost much more and probably had a value (2300 pounds) of $6.00 to $10.00 in the field for hay. The use of soybeans for green manuring for 30 years did not increase the organic matter in the soil.

The data on wheat reported in Table 14 were obtained at the New Jersey Experiment Station (8) using soybeans for green manure.

Table 14.—THE EFFECT OF SOYBEAN GREEN MANURE ON THE YIELD OF WHEAT.

	3-year average yield of wheat per acre
After soybean hay..	16 bushels
After soybean hay plus 300 pounds of nitrate of soda.........	31 bushels
After 67 pounds of nitrogen in soybean green manure.........	25 bushels
After 67 pounds of nitrogen in soybean green manure and 300 pounds of nitrate of soda..............................	33 bushels

For wheat production, a crop of soybeans was about half as valuable as 300 pounds of nitrate of soda. The value of the soybeans for feed was several times the cost of nitrate of soda to give the same increase in yield of wheat. The cost of the soybean green manure crop was probably at least twice the cost of the nitrate of soda.

The yield of cotton per acre has increased since the Agricultural Adjustment Administration began its program. The yield of seed cotton, tons of fertilizer used, and the winter legume seed planted in Mississippi (17)[1] are reported in Table 15. The winter legume seed

Table 15.—THE RELATION OF WINTER GREEN MANURES AND FERTILIZERS TO THE YIELD OF COTTON IN MISSISSIPPI.

Year	Yield of lint cotton	Commercial fertilizer used	Winter legume seed[1]
	Pounds per acre	Tons	Pounds
1930.	169	312,159	....
1931.	211	154,044	1,742,175
1932.	149	61,613	1,444,225
1933.	196	101,111	2,575,000
1934.	215	163,598	2,842,040
1935.	228	176,561	5,500,000
1936.	305	219,250	9,191,560
1937.	372	300,561	14,417,828
1938.	322	265,182	19,229,282
1939.	300	285,666	26,567,926
1940.	235	294,036	25,330,230
1941.	285	325,520	33,046,936
1942.	396	340,205	34,119,163

[1]Planted the fall before; plowed under before cotton as indicated.

planted increased from 1,742,175 pounds in 1930 to 34,119,163 pounds in 1941-42. The big increase in use of winter legumes took place from 1934 to 1939. The yield of cotton per acre almost doubled over this period. In 1939, the 26,567,926 pounds of winter legume seed at 26.5 pounds per acre planted approximately 1,000,000 acres. If 60% of the acreage was turned for cotton, 600,000 acres or 24% of the cotton acreage in 1939 received a green manure crop. The average increase in yield of lint cotton obtained by farmers was 100 pounds per acre (20) from the use of winter legumes. On this basis, green manure crops increased the average yield of lint cotton 24 pounds per acre. This small increase in yield accounts for only a small part of the increase in yield obtained. It appears that the larger yields of cotton from 1936

1 Other data also.

to 1939 were due to the season, measured acres, selection of soils, and improved cultural practices.

Different summer legumes affect the yield of the following crops differently as data (25) from Kentucky reported in Table 16 show.

Table 16.—THE EFFECT OF TYPE OF HAY CROP ON THE YIELD OF CORN AND WHEAT.

Treatment	Yield of corn[1] per acre	Yield of wheat per acre
	Bushels	Bushels
1 ton lespedeza plowed under...................	44	12
Lespedeza for hay.............................	37	11
Cowpeas for hay..............................	30	8
Soybeans for hay.............................	29	8
Soybeans for seed............................	33	9

[1]Corrected to uniform check.

Plowing under one ton of lespedeza hay increased the yield of corn only 7 bushels per acre over that obtained after lespedeza stubble. When lespedeza was cut for hay the yield of the following crop was much superior to that obtained after cowpea and soybean hay crops. More crop residue was probably left on the ground after lespedeza for hay than where cowpeas or soybeans were grown. The data also show that lespedeza for hay, alfalfa for hay, alfalfa for hay with the last crop turned under, clover for hay, and sweet clover for hay one year and seed (straw returned) the next year were about equal for increasing the yield of the following crop.

FIG. 3.—The cotton on the left was produced after 4 years of unharvested lespedeza; after soybeans on right. (Courtesy Mississippi Agricultural Experiment Station.)

FIG. 4.—Crotalaria produces a volunteer crop after the last cultivation of corn. (Courtesy Soil Conservation Service.)

Soybeans in corn increased the yield of seed cotton 340 pounds per acre when plowed under in the fall, and 430 pounds per acre when turned in the spring in Alabama (31). These experiments were conducted in concrete bins, and the data may not be applicable in the field. In Georgia (1) 208 pounds increase in yield of seed cotton was obtained from turning 1,793 pounds per acre of air-dry cowpea hay into the soil in the fall, and no increase was obtained where cowpeas were plowed under in the spring. The data on date of turning under summer green manure crops for summer crops to follow are in disagreement, and no conclusion can be reached on this subject.

Crotalaria which has produced a heavy crop of seed often reseeds in corn for several years. The practice has reportedly made excellent increases in the yield of corn. With this system, a crop of young crotalaria plants is turned under at each cultivation of the corn. This practice appears to be valuable for both cotton and corn on many soils.

Crotalaria spectabilis and oats controlled nematodes or root knot on peach trees in Georgia (12), and the crotalaria supplied nitrogen to the trees:

Treatment	Yield—lbs. of peaches per tree—second crop
Clean cultivation.......................	25
Cowpeas in summer, Austrian winter peas in winter..............	5
Oats in winter, Crotalaria spectabilis in summer............	65

Crotalaria spectabilis in the summer, followed by oats in the winter, practically eliminated the root knot organism; clean cultivation also practically eliminated the root knot organism, but root knot was increased by Austrian winter peas and cowpeas.

Korean, common, Kobe, Tennessee 76, and serecia lespedeza were found to increase nematodes (12), which suggests that these crops, as well as cowpeas and Austrian winter peas, should not be planted where root knot susceptible crops are to be grown later.

Kudzu and serecia lespedeza are excellent crops for corn or cotton to follow in the Southeast. However, it takes from one to two years to establish either crop, and they are too expensive to establish to be

FIG. 5.—A yield of 40 bushels of corn per acre was made after three years of kudzu for hay and grazing, and the kudzu was re-established (7). (Courtesy Soil Conservation Service.)

used for increasing the yields of other crops. Also, the cost of producing hay with these crops after being established is probably considerably less than with other hay crops.

The effect of kudzu on the yield of corn[1] was determined in 22 tests in Alabama (Table 17). In most cases kudzu had been on the

Table 17.—THE EFFECT OF KUDZU ON CORN YIELDS.

Test No.	Land use prior to planting kudzu	Date kudzu planted	Corn yield bus. per acre[1]		Growth of kudzu in corn
			Before kudzu	After kudzu	
1	Cultivated.......	1936	7	27	Good
2	"	"	15	39	Fair
3	Idle............	1935	3	17	Good
4	"	"	10	38	"
5	"	"	12	28	"
6	Cultivated.......	"	10	22	Fair
7	"	1936	6	33	Good
8	Idle............	"	4	20	"
9	Cultivated......	"	12	32	"
10	"	1932	10	35	"
11	"	1926	10	41	"
12	Idle............	1930	5	28	Poor
13	Cultivated.......	1936	8	44	Good
14	Idle............	"	5	35	"
15	Idle............	"	8	32	Fair
16	"	"	5	30	Good
17	No information...	"	..	35	"
18	" " ...	"	..	29	"
19	Cultivated.......	1934	5	38	Fair
20	"	....	5	15	....
21	"	1936	4	21	Good
22	"	"	4	30	"
		Average	7	30	....

[1]The kudzu was plowed for corn in 1940.

land for four years or longer. Kudzu increased the average yield of corn 23 bushels per acre, and the recovery of the kudzu in the corn was either fair or good in all but one test, where the recovery was poor. The information which the author has is that corn can not be planted more often than every other year if kudzu is to be maintained.

The economic evaluation of the data on the use of the kudzu and corn rotation is difficult. The increase in yield of corn from 200 pounds of ammonium nitrate, which costs about $5.50 annually, would be expected to be 23 bushels of corn per acre, which suggests that the value

[1]Data supplied by E. C. Richardson of the Soil Conservation Service and the Alabama Polytechnic Institute.

of the kudzu for increasing the yield of corn is $5.50 per acre every other year. The value of the kudza may be largely offset by the increase in the labor of preparing the land, and harvesting the corn.

It should also be pointed out that the use of the kudzu for hay and grazing may fit into the farming program and be profitable. Since the cost of establishing hay and grazing crops is usually more than $5.50 per acre, it appears that kudzu should not be plowed for corn when once established until for some reason it loses its usefulness for hay and grazing.

It is recognized that alternating kudzu and corn on steep land may enable the use of land for corn which could not be used for row crops continuously.

The gain in soil nitrogen from long periods of sod crops is depleted in a short time after the land is brought into clean cultivated crops. The data reported in Table 18 were obtained after seven years of

Table 18.—The Yield of Corn after Sod Crops.

Year after serecia	Years test conducted											Average	Cumulative percent of increase
	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943		
	Yield—bushels corn per acre												
1	70	63	79	64	74	71	79	69	53	73	65	69	23
2	..	62	59	68	61	64	76	63	66	56	70	65	43
3	..	..	58	54	55	54	57	60	59	55	65	58	60
4	..	..	..	53	41	52	45	53	56	50	57	51	73
5	..	..	..	..	39	37	42	42	53	44	48	44	83
6	..	..	..	..	..	32	32	36	48	42	47	39	89
7	..	..	..	..	..	..	27	27	45	37	42	36	94
8	..	..	..	..	..	..	..	26	35	43	40	34	98
9	..	..	..	..	..	..	..	..	31	26	33	30	99
10	..	..	..	..	..	..	..	..	..	26	30	28	100
11	..	..	..	..	..	..	..	..	..	..	27	27	...

various clovers, grasses, and annual lespedeza followed by 3 to 13 years of lespedeza serecia (23). After three years of serecia part of the area was plowed up each year for ten years and planted to corn each year until the close of the experiment.

The 1933 corn plots were planted after 3 years of serecia and seven years of other sod crops; the first year corn plots of 1943 were planted after 13 years of serecia and seven years of other sod crops, or a total of 10 and 20 years of sod crops, respectively. The serecia was cut for hay.

The high yields obtained the first few years after breaking the sod are attributed to the nitrogen which was released from the organic matter which accumulated under the sod crops. There is no indication

that 20 years of sod crops was better than 10 years. The minimum time in sod crops necessary to get a similar increase in soil nitrogen as reflected in corn yields is not indicated by the data.

The yield of first-year corn after sod crops was 42 bushels per acre more than on the eleventh year of continuous corn after sod crops. The yield of unfertilized corn on the eleventh year after the sod crops was comparable to the yields on other near-by plots which had been in clean cultivation for a long period of time. The yield of corn declined quite rapidly under continuous corn.

On breaking the sod the accumulated organic matter decomposed rapidly, liberating its nitrogen for the corn crop which followed. As reflected by the yield of corn, 23% of the total increase due to sod crops was obtained the first year after breaking, 43% in two years, 60% in three years, 73% in four years, 83% in five years, 89% in six years, 94% in seven years, 98% in eight years, 99% in nine years, and 100% in 10 years.

Even though the long period in sod crops increased the corn yield markedly, 73% of the total increase in yield was obtained in four years after breaking the sod. The increase in soil nitrogen as reflected by corn yields had largely disappeared in seven years. These data suggest that it is necessary for sod crops to occur frequently in rotations where they are to be depended upon to supply nitrogen for clean cultivated crops.

The roots of a good crop of vetch increased the yield of corn 7 bushels per acre (3) in Mississippi. Turning under the tops gave an additional increase of 10 bushels of corn per acre. Vetch roots contain 35% of the total nitrogen in the plant. The stubble of crimson clover was practically as effective as the whole plant (32) for increasing the 5-year average yield of corn in Tennessee. The increase in yield of corn was 11 bushels per acre for crimson clover stubble, and 13 bushels for the whole plant. In Virginia (32) the 8-year average yield of corn was increased 11 bushels after crimson clover and vetch for hay, and 15 bushels after turning under the legumes. Soybean stubble produced only 40 pounds less seed cotton than approximately one ton of soybean hay in addition to the stubble (16) in Mississippi.

The value of good yields of legumes for obtaining nitrogen from the air to be used by the following cash crop has been well established. Crops on soils low in nitrogen generally give profitable response to nitrogen from legumes, where a good yield of the legume is produced. For this reason, winter legumes and second year clovers are usually more profitable than summer legumes when their sole use is for soil

improvement. Usually, sod crops like the clovers, lespedeza, and alfalfa increase the yield of the following crop more than crops like soy- beans and cowpeas.

When legumes are grown primarily to get nitrogen from the air to increase the yield of the following crop, the economy of the practice is doubtful with the present low price of nitrogenous fertilizers—not that legumes are not profitable, but that the same income can generally be obtained for the expenditure of less for commercial nitrogenous fertilizers. Of course, there are exceptional cases where money invested in legumes for green manuring is more profitable than an equal amount spent for commercial nitrogen.

The value of green manure crops for grazing depends upon the amount of green material present. Even though no data are available on the growth of the crops, the gains in steer weight reported in Table 19 were produced in Georgia (2) from the crops indicated. The oats

Table 19.—CULTIVATED CROPS FOR BEEF PRODUCTION.

Crop	Years	Pounds of steer per acre	Value at 6 cents per pound
Kudzu..............................	6	247	$14.82
Oats and hairy vetch................	1	110	6.60
Cat-tail millet......................	1	219	13.14
Oats and hairy vetch, and cat-tail millet.	1	329	19.74
Ryegrass...........................	1	105	6.30
Otootan soybeans....................	1	159	9.54
Ryegrass and Otootan soybeans.......	1	264	15.84
Oats...............................	1	89	5.34
Common lespedeza...................	1	106	6.36
Oats and common lespedeza..........	1	195	11.70
Velvet beans.......................	1	11	0.66
Abruzzi rye........................	1	59	3.54
Velvet beans and abruzzi rye........	1	70	4.20

and vetch were grazed from December 18 to May 3 and made 110 pounds of beef worth, at 6 cents per pound, $6.60. Less beef would be obtained where oats and vetch are plowed under for an early crop like cotton. Otootan soybeans produced 159 pounds of beef valued at $9.54 per acre. In addition to the livestock income the value of the manure for increasing the yield of the following crop was probably almost as much as the value of the green manure had grazing not have been practiced. **An increase in steer weight of 305 pounds per acre from a lespedeza-grain pasture was obtained by the Missouri Experiment Station in 1937 on 20-bushel per acre corn land (15).**

Kudzu grazed from June to September produced 128 pounds of

beef per acre per year in Alabama (13) for 5 years. The kudzu furnished grazing at a time of the year when pasture grasses are usually short. Sweet clover and clover pasture in a crop rotation is widely used in the Middle West. The soundness of the practice is evident. Where cultivated land can be rotated with temporary pastures profitably, the practice will result in increased soil nitrogen where close-growing non-cultivated crops are grown. Temporary non-cultivated crop pasture should have practically the same effect on soil fertility as devoting land to weeds and grass, the value of which is well known.

In so far as temporary pastures can be rotated with cultivated fields and hay fed on the temporary pastures, the depletion of phosphorus and potash by hay and similar crops is reduced. The depletion of phosphorus and potash by hay crops is primarily a process of removing these elements from hay land and redepositing them on pasture land or where the cows drop manure. Feeding of hay on pasture land and rotation of crop and pasture land, evidently, will tend to keep these elements evenly distributed over the farm land.

In a grazing program where the manure falls on the land (no data available), the value of legumes for increasing the yield of the following crop should be reduced an insignificant amount by livestock having consumed the legume first. Since, in the process of digestion, the animal brings about partial decomposition of the legume which continues in the manure, the consumption of green manure crops by animals probably does not significantly reduce their value for increasing crop yields. The value of rye, oats, wheat, and barley for increasing the yield of the following crop is probably increased by animals' eating them before they are turned into the soil.

Where animals consume a large part of a green manure crop before it is turned into the soil, less green material is present to turn under, which should reduce the power required to prepare the seed bed, the time necessary to wait after preparing the seed bed before planting the crop, and stand injury, which often results after plowing under heavy green manure crops.

SUMMARY AND CONCLUSIONS

Before nitrogenous fertilizers were known or before they came into general use, legumes were often used to supply nitrogen for crops which followed. After the introduction of these fertilizers a choice could be made concerning the use of legumes or commercial fertilizers to supply nitrogen. Until recent times nitrogenous fertilizers were expensive; at the present time they are relatively cheap, and the indi-

cations are that they may be cheaper in the future. With cheap nitrogenous fertilizers available the use of legumes to supply nitrogen primarily may be too expensive. Legumes are of much more importance where they are consumed by livestock first, and manure and crop residues are turned under for the following crop, than where they are grown primarily to supply nitrogen.

The data reviewed on the use of legumes to supply nitrogen to other crops show:

1. Annual summer legumes are too expensive to be used for increasing the yield of the crops which follow.
2. Winter legumes have been successful on very fertile sandy soils.
3. Winter legumes have not been successful on poor soils.
4. Winter legumes have usually grown well when they have received liberal amounts of superphosphate; however, the cost of the extra fertilizer may make the cost of winter legumes greater than the cost of obtaining a similar yield from commercial nitrogen.
5. Legumes which live for two or more years have been much more valuable for soil improvement than annual legumes.
6. Soybeans and cowpeas in corn for increasing the yield of the following crop have not been found to be generally profitable.
7. Plowing land in the fall to plant winter legumes increases soil erosion.
8. Legumes which can be grown successfully have a very definite place where they can be consumed by livestock before being turned into the soil. Where legumes are grown for livestock first and for increasing the yield of the following crop secondly, they will be more widely used than where they are grown for one purpose only.
9. In most cases legumes should be planted for animals to eat, and the unconsumed residues and as much of the manure as possible should be returned to the soil.
10. The application of phosphate to winter legumes will not take care of the phosphate needs of cotton on soils deficient in phosphorus. Cotton is more sensitive to a deficiency of phosphorus than vetch or Austrian winter peas.

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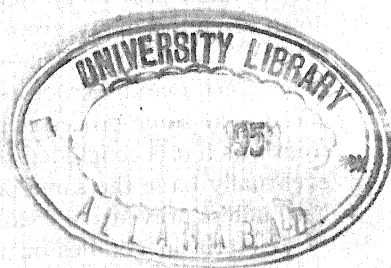
The Effect of Leguminous Green Manures on the Lime and Potash Content of the Soil

Nitrogen which leaches out of the soil carries potash and lime out in the drainage water.

Farmers on soils of low fertility have made the following comments on results obtained with leguminous green manure crops. "Vetch grew well for a few years and increased the yield of cotton considerably, after which it failed to grow, and the following cotton crop had an unthrifty appearance"; "Vetch does better on land which has not grown vetch previously than it does on old vetch land"; "Corn falls down after too many green manure crops". Farmers on soils of high fertility have not experienced the same unfavorable results with leguminous green manure crops as those on soils of low fertility have experienced. The same processes are going on in both poor and fertile soils, from which it is concluded that farmers on the more fertile soils should eventually have the same poor results as those on the poor soils have had, unless preventive treatments are applied.

Bacteria in nodules on the roots of legumes take nitrogen out of the air, which is used by the legume plant. The nitrogen is used to build proteins, which become a part of the plant. Upon turning the legume into the soil the plant is decomposed, and the nitrogen is changed to ammonia nitrogen. The ammonia nitrogen is either used by plants or changed into nitrate nitrogen. The nitrate nitrogen is used by plants and removed in the harvested crop, or it leaches out of the soil in the drainage water. Nitrate nitrogen leaches out of the soil because nitrates are soluble in water. Clay combines with ammonia nitrogen. Since clay particles are too large to leach out of the soil, the ammonia

nitrogen on the clay does not leach out of the soil readily. However, all nitrates are soluble in water, and they are subject to leaching.

It is generally agreed by all who have studied the effect of nitrogenous fertilizers on the lime content of the soil that:

1. Nitrogen from cottonseed meal, urea, and ammonium nitrate leaches lime and potash out of the soil.
2. Nitrogen from sulphate of ammonia and ammonium phosphate decreases the lime and potash content of the soil; in addition, the sulphate and phosphate decrease the lime content of the soil.
3. Nitrogen from nitrate of soda and calcium nitrate decreases the lime content of the soil, but these decreases are offset by the increase produced by the soda and lime added in these fertilizers.

The extent to which nitrogen from the above sources reduces the lime and potash content of the soil depends upon the quantity of applied nitrogen, which is not used by plants. The nitrogen which is taken out of the air by legumes is eventually converted into nitrates, which are either used by plants and removed in the harvested part of the crop or leached out of the soil as calcium nitrate, magnesium nitrate, nitrate of soda, and potassium nitrate.

The loss of nitrogen in the drainage water under different legumes, blue grass, and rye and blue grass legume combinations was determined by the Kentucky Agricultural Experiment Station (4)[1] where the tops of plants were harvested and removed from time to time (Table 1). During the first, second, and third years more nitrogen was lost from Korean lespedeza, which dies each year and reproduces from seed, than from white clover, red clover, and alfalfa, which live for more than one year. The leaching of nitrogen from red clover, which lives two years, was much greater on the year it died. Very little nitrogen was leached from the soils on which blue grass was growing with legumes except with lespedeza, where blue grass reduced the leaching of nitrogen by half. Rye planted in the fall after lespedeza reduced the loss of nitrogen by leaching from 97 pounds to less than one pound per acre in 1935-'36. Very little nitrogen was lost where alfalfa was grown. Alfalfa grows from old crowns each year, and few roots and stubble are decomposed to give up nitrogen. Large quantities of nitrogen were lost where no crop was grown.

Disking lespedeza into the soil (Kentucky) more than doubled the loss of nitrogen by leaching as compared to leaving it undisturbed. Planting rye October 1 conserved all of the nitrogen where lespedeza

[1]Numbers in parenthesis refer to the source of information, page 170.

Table 1.—THE EFFECT OF LEGUMES AND GRASSES ON THE LEACHING OF NITROGEN FROM SOIL IN TANKS.

Tank No.	Vegetation[1]	Oct. 10, 1933 to March 31, 1934	April 1, 1934 to March 31, 1935	April 1, 1935 to March 31, 1936	April 1, 1936 to March 31, 1937
		Pounds of nitrogen leached per acre			
1, 2	Korean lespedeza.........	20.6	97.7	79.2	60.4
3, 4	White clover.............	7.2	20.8	42.6	186.8
5, 6	Red clover..............	5.3	7.4	43.1	192.7
7, 8	Alfalfa.................	5.1	0.	10.1	3.3
9, 10	Bluegrass...............	4.9	12.2	0.3	3.3
11, 12	Korean les., rye cover crop..................	5.5	0.3	26.5	9.6
13, 14	Korean les., bluegrass.....	5.6	34.9	55.6	34.9
15, 16	White clover, bluegrass...	5.6	1.6	5.2	4.9
17, 18	Red clover, bluegrass.....	8.2	11.8	9.8	5.9
19, 20	Alfalfa, bluegrass	4.7	0.	2.4	4.6
21, 22	None..................	29.4	165.3	114.8	99.7

[1]The vegetation has not been vigorous in certain lysimeters at times, resulting in greater leaching of nitrogen in these than otherwise would have occurred.

was disked (4) into the soil (Table 2). Rye and other crops use nitrogen which would be leached out of the soil as the nitrate of calcium or other bases. Crops also reduce leaching of nitrogen by using water which would have leached out of the soil. Fall crops must be planted early enough to produce a good growth before cold weather in order to conserve significant quantities of nitrogen. Young non-legumes containing 2% nitrogen would have to produce 1,000 pounds of dry material per acre to keep 20 pounds of nitrogen from leaching out of

Table 2.—THE EFFECT OF TIME OF DISKING LESPEDEZA INTO THE SOIL AND RYE ON THE LOSS OF NITROGEN BY LEACHING.

Tank No.	Treatment	Oct. 1, 1934 to Mar. 31, 1935	April 1, 1935 to June 30, 1935	Total Oct. 1, 1934 June 30, 1935
		Pounds of nitrogen leached per acre		
1, 2	Korean lespedeza disked into the soil Oct. 1. No cover crop...................	97	30	127
11, 12	Korean lespedeza disked into the soil Oct. 1 and rye seeded................	0	2	2
13, 14	Korean lespedeza not disturbed................	35	21	56

the soil. Only a very small percentage of the soils are capable of producing 1,000 pounds of rye or other grain crops before cold weather. Under most farming conditions it, therefore, appears that fall-planted non-legumes will conserve little nitrogen.

The effect of the loss of soil nitrogen by leaching was explained as follows by Roberts (9) of Kentucky:

"In the process of becoming soluble, nitrogen is converted into nitric acid, a very strong acid which combines with important elements in the soil, such as calcium and potassium, among other elements, to form soluble compounds which are subject to leaching, thus causing the loss of these mineral elements as well as nitrogen."

The use of legumes to supply nitrogen to the following crops has not been as successful in the South and Southeast as in the Middle West. The reason for the difference in the success in the two areas may be explained by the following data:

1. From the Mississippi Delta, where winter legumes plowed under just before planting cotton have been highly successful:

Treatment	Nitrogen—pounds per acre		
	Plowed under	Harvested in cotton	Not harvested
Austrian winter peas	61	10	51
Hairy vetch	84	14	70
Sweet clover	54	8	46
Bur clover	111	10	101
Nitrate of soda	30	7	23

2. From Illinois (2), where a corn, oat, sweet clover rotation has been successful:

	Pounds
Nitrogen plowed under	34.4
Nitrogen harvested in crop	30.4
Nitrogen leached out of the soil	4.0

In the Mississippi Delta an average of 14% of the nitrogen was harvested and 86% was not recovered; in Illinois 88% of the nitrogen was harvested and only 12% was lost over an 8-year period. The loss of nitrogen by leaching from legume crops which are turned under is very significant in warm climates, particularly on well-drained soil. Nitrate nitrogen leaches calcium, magnesium and potash out of the

soil with it. The low loss of nitrogen by leaching reported in the Illinois experiments may be less than is normally obtained.

The lime needed to neutralize the soil acidity of the soil in Rhode Island was 2,861 pounds without green manure, 3,027 after rye, and 4,405 pounds after clover (3). The green manures were planted each year when corn was laid by. The period of time was not stated definitely, but it was probably about 15 years. The rye green manure had no effect on the lime needed, but the legume increased the lime needed by more than 1500 pounds per acre. Turning under 99 pounds of nitrogen per acre in crotalaria in January had no effect on the nitrate nitrogen in sandy soil by the middle of June on the following year in Florida (10). Most of the nitrogen turned under in the crotalaria was converted into nitrates, which leached out of the soil before June.

The effect of the growth of crotalaria on the nitrogen, calcium, and potash lost by leaching was determined at the South Carolina Experiment Station (6). Crotalaria was grown in two tanks for one year, after which one tank was planted to millet for 2 years. The millet was harvested. The other tank was continued in crotalaria, which was cut each fall and left on the surface of the soil. The soil where crotalaria was grown lost the following amounts of plant nutrients in the drainage water more than was lost where millet grew:

Nitrogen	87 pounds per acre
Lime, including magnesium	190 pounds per acre
Potash	11 pounds per acre

In a similar test, rye as a winter cover crop reduced the leaching of nitrogen and other elements from the crotalaria tanks to about the same low level as where millet was grown and harvested. Rye reduced the leaching of nutrients by using them for plant growth, and by using water which would have leached through the soil.

The effect of vetch on the accumulation of applied potash in the subsoil in a rotation in Alabama (12) is shown by the data in Table 3. Twenty-four pounds of potash per acre each year or a total of 192 pounds was applied during the 8-year period. Without vetch in the rotation an average of 39 pounds of the 192 pounds of applied potash accumulated in the subsoil. Generally the soils with the more sandy subsoil had a greater accumulation of applied potash in the subsoil. No data were reported for the topsoil. With vetch in the rotation, an average of only 6 pounds of the applied potash accumulated in the subsoil as compared to an average of 39 pounds without vetch in the

rotation. Without vetch 62 pounds of the potash applied to Norfolk very fine sandy loam accumulated in the subsoil; with vetch only 4 pounds of the applied potash accumulated in the subsoil.

Two reasons have been suggested for less potash accumulating in the subsoil where vetch was grown. The first is that vetch prevented the leaching of potash below the 8-inch layer. If vetch prevented potash from leaching below the 8-inch depth, it would have had to tie up large quantities of potash in living plant material over a large

Table 3.—THE EFFECT OF VETCH ON THE POTASH CONTENT OF SUB-SOILS.

Soil type	Sub-soil class	Pounds of applied potash accumulating in the 8 to 24 inch layer	
		No winter legumes in rotation	Winter legumes in rotation
Kalmia very fine sandy loam.....	Clay.............	17	5
Greenville clay.................	Clay.............	23	5
Hartselle very fine sandy loam...	Sandy clay loam...	35	0
Decatur clay....................	Clay.............	38	7
Orangeburg fine sandy loam.....	Clay.............	41	12
Decatur clay....................	Clay.............	44	7
Norfolk sandy loam.............	Sandy loam.......	50	8
Norfolk fine sandy loam.........	Sandy clay loam...	62	4
Average........................	....	39	6

part of the year or reduce the amount of water percolating through the soil. A heavy growth of vetch normally exists on the land for about one month in the spring before plowing for cotton or corn. Growing vetch reduces leaching to a small extent by consuming water which is transpired into the air. The production of 1,000 pounds of air-dry vetch per acre could reduce the leaching of water by about 2 inches if evaporation and run off were not affected.

Since the potash in crop residues in the soil is soluble in water, the vetch could not have reduced the leaching of unharvested potash significantly for about 10 or 11 months of the year. The Alabama Experiment Station found that sulphate of ammonia increased soil acidity significantly below the 8-inch depth, and increasing soil acidity is usually associated with a depletion of potash as well as calcium and magnesium. That winter legumes prevented the leaching of potash out of the surface soil does not appear to be sufficient reason for the failure of potash to accumulate in the subsoil.

The leaching of potash out of the soil in the drainage water as potassium nitrate is offered as a second explanation for the failure of potash to accumulate in the subsoil where vetch was grown. This explanation is in harmony with the conclusions from other data on this subject, and with the accepted effects of nitrogen applied in commercial fertilizers which is not removed in the harvested crop, upon the supply of calcium, magnesium, and potash in the soil.

Soybeans and vetch green manures did not reduce the amount of available lime and potash in a soil over a nine-year period in Alabama (11). The data reported suggested to the authors of the paper that at least 25 pounds of nitrogen per acre as the nitrate was lost by leaching

Table 4.—The pH Values of Greenville and Norfolk Sandy Loam Soils Following Various Cropping Systems.

Type of cropping system[1]	Greenville sandy loam[2]					Norfolk sandy loam[2]				
	Average green weight	1935	1936	1937	1938	Average green weight	1935	1936	1937	1938
	Pounds	pH	pH	pH	pH	Pounds	pH	pH	pH	pH
A, Winter green manure.....	7,688	6.0	5.6	5.6	5.1	9,017	5.7	5.8	5.8	5.2
B, Winter and summer green manure (largely legumes)..	29,381	6.0	5.8	5.5	5.1	26,190	5.6	5.5	5.5	5.1
C, Summer green manure....	14,081	5.9	5.8	5.5	5.3	14,266	5.7	5.3	5.6	5.2
D, Winter grain and summer legume.................	32,115	5.9	5.7	5.6	5.5	41,034	5.7	5.7	5.7	5.4
E, Winter grain and summer legume (not fertilized).....	11,696	6.1	5.8	5.8	5.7	3,937	5.9	5.6	5.8	5.5
F, Kudzu permanent cover..	11,217	5.6	5.6	5.5	5.8	10,275	5.6	5.3	5.5	5.3
G, Bermuda grass sod.......	6,926	5.7	5.7	5.5	5.5	2,548	5.8	5.8	5.6	5.4
H, Cash crop rotation with summer legumes..........	14,157	5.8	5.6	5.6	5.3	12,698	6.0	5.9	5.6	5.3

[1]A 4-8-4 fertilizer was applied at the rate of 400 pounds per acre annually except as noted.
[2]The original pH of Norfolk and Greenville soils in the fall of 1934 was pH 5.8.

each year from fall-turned soybeans, which makes a total loss of more than 225 pounds over the nine-year period. Since nitrate is lost primarily as calcium nitrate, it appears that the 225 pounds of nitrate nitrogen should have removed the equivalent of 225 x 3.57 or 803 pounds of lime over the period. The data show that this loss did not take place. The results are not in agreement with other data on the subject.

The effect of green manure crops on the pH of the soil was determined on two soil types in Georgia (5). The data are reported in Table 4. The tests were started in the fall of 1934 in a pecan orchard, at which time both soils had a pH of 5.8. Both winter and summer legumes reduced the reaction of the soil from pH 5.8 to just above pH 5.0 in four years. The use of winter grains with summer legumes kept the pH from falling so low; the use of the winter grains caused 300 pounds

per acre more nitrogen to be retained in the soil organic matter than where summer legumes were not followed by winter grains. The higher pH where winter grains followed summer legumes is no doubt due to the reduction in the amount of lime and potash lost by nitrogen leaching them out of the soil.

Without fertilizer summer legumes and winter grains made very little growth and reduced the pH of the soil less than where fertilizer was used and more growth was made. Kudzu maintained the pH on Greenville soil and reduced it on Norfolk.

The effect of winter legumes and rye on the pH of the soil in a cotton and corn rotation was determined in Georgia (5). The pH of the soil in 1926 was 6.1. In 1939 the pH was as shown in Table 5. The

Table 5.—THE EFFECT OF WINTER COVER CROPS ON THE PH OF THE SOIL.

	Nitrogen in fertilizer	No nitrogen in fertilizer
	pH	pH
Monantha vetch	5.4	5.3
Hairy vetch	5.2	5.3
Austrian winter peas	5.35	5.3
Abruzzi rye	5.7	5.7
No green manure	5.8	5.5

winter legumes reduced the pH of the soil from pH 5.8 to about pH 5.3 where nitrogen was used in the fertilizer. The lowering of the pH where the winter legumes were grown was no doubt due to leaching of calcium and other bases out of the soil by nitrate nitrogen. Rye had no significant effect on the pH of the soil. Without nitrogen in the fertilizer, the legumes lowered the pH of the soil, and rye increased it slightly.

Since potash is about 20 times as expensive as lime, the cost of maintaining the base content of the soil increases where part of the nitrogen is leached out as potassium nitrate. Where soils are low in bases, less than 3.57 pounds of lime or its equal in potash and magnesium will be leached out. However, the figure may be approximately correct for soils which are sufficiently fertile to grow a good legume crop.

The pounds of nitrogen which 1,000 pounds of water dissolves in different nitrates is shown by the following data:

    Magnesium nitrate...218
    Calcium nitrate...174
    Potassium nitrate..17

These data suggest that nitrates will be lost largely as calcium and magnesium nitrates, where high amounts of calcium and magnesium are present in the soil. Where the soil contains small quantities of calcium and magnesium, the loss of potash as the nitrate will be greater. The need for keeping soils well limed where leguminous green manure crops are grown is evident.

The use of vetch green manure decreased the pH of the soil significantly in a test conducted in Texas (Table 6) where cotton was

Table 6.—The Effect of Vetch Green Manure on the pH of the Soil.

Treatment for cotton	Average yield of air-dry vetch 1937-42 tons per acre	Average pH 1940, 41, 42
Vetch, 4-8-4	1.37	4.60
Vetch, 0-8-4	1.31	4.60
Vetch	0.91	4.65
Untreated	....	5.02
4-8-4	....	5.12

grown (7). The vetch green manure reduced the pH from 5.12 to 4.60 with fertilizer and from pH 5.02 to 4.65 without fertilizer treatment. The pH decreased more on adjoining areas where vetch was grown and no summer crop followed it.

The effect of different green manuring practices on the loss of plant nutrients by leaching was determined by tests conducted in tanks in South Carolina (8). The soil used was Norfolk coarse sandy loam. The data are reported in Table 7. The cropping systems used resulted in loses of nitrogen by leaching of 66 to 180 pounds per acre. As the loss of nitrogen by leaching increased:

(a) The loss of lime by leaching increased,
(b) The loss of magnesium by leaching increased,
(c) The yield of cotton decreased, and
(d) The yield of rye decreased.

The decreases in the yield of cotton and rye are no doubt due to a decrease in plant nutrients, which was brought about by nitrogen leaching them out of the soil. The four soils which lost the most nitrogen by leaching lost 78 pounds of nitrogen, and lime, magnesium, and potash equal to 292 pounds of lime per acre, more than the four soils which lost the least nitrogen, or 3.74 pounds of lime per pound of additional

nitrogen lost by leaching. The loss of 3.74 pounds of lime per pound of nitrogen approaches the theoretical loss of 3.57 pounds of lime per pound of nitrogen closely.

The calculated loss of 3.57 pounds of lime or its equal in potash and magnesium for each pound of nitrogen which is not harvested in crops is in error to the extent that nitrogen goes off into the air as

Table 7.—THE EFFECT OF SUMMER AND WINTER CROPS ON THE LEACHING OF PLANT NUTRIENTS FROM NORFOLK COARSE SAND IN TANKS.

Tank No.	Treatment[1]			Yield of green material per acre		Leached out of soil winter 1940-41 and summer 1941				
	Summer		Winter 1939-40 1940-41	Win-ter 1940-41	Sum-mer 1941	Water	Potash	Lime	Mag-nesium[2]	Nitro-gen
	1940	1941								
				Tons	Tons	Inches	Pounds per acre			
23	Cotton....	Cotton....	Rye......	3.5	2.4	15.7	23	207	87	66
19	Crotalaria striata....	Crotalaria striata....	Rye......	5.5	7.8	9.7	16	194	80	91
1	Crotalaria striata....	Cotton	Rye......	5.4	2.7	12.8	13	251	108	99
20	Crotalaria spectabilis.	Crotalaria spectabilis.	Rye	4.5	5.8	13.6	26	285	123	116
24	Fallow....	Fallow....	Rye......	...	...	21.4	42	413	194	137
5	Crotalaria striata....	Cotton....	Fallow...	0.0	1.7	17.4	21	413	178	156
7	Crotalaria striata....	Cotton....	Vetch....	1.9	1.7	16.0	20	414	176	172
3	Crotalaria striata....	Cotton....	Vetch....	1.3	1.3	16.9	21	449	185	177
4	Crotalaria striata....	Cotton....	Austrian winter peas.....	2.0	1.2	16.0	24	463	197	180

[1]The plant material produced in the winter of 1939-1940, and in the summer of 1940 was turned into the soil.
[2]Calculated equal to lime.

ammonia. However, convincing proof that the loss of nitrogen into the air as ammonia is significant under normal conditions has not yet been presented. The calculations below illustrate the effect of legumes on the base content of the soil, calculating the loss of calcium, magnesium, and potash as pure lime. The hairy vetch contained an average of 84 pounds of nitrogen per acre in tops. The increase in yield due to vetch was 727 pounds of seed cotton. The calculations are as follows:

	Pounds
Nitrogen applied in vetch................................	84.0
Nitrogen harvested in seed cotton 727x2%................	14.5
Nitrogen lost...	69.5
Lime lost calculating all bases as lime 69.5x3.57............	248.0
Excess of lime lost over acids in seed cotton 727x0.89%......	5.0
Total lime lost..	253.0

If each pound of nitrate nitrogen which leaches out of the soil carries the equivalent of 3.57 pounds of lime, 250 pounds of lime should be added each year or larger amounts at less frequent intervals in a vetch and cotton program to keep the soil from being depleted of its bases where an average of 84 pounds of nitrogen in green manure crops is turned under each year. After a few years of green manuring when the organic matter content of the soil becomes constant, as much nitrogen is lost each year as is added to the soil.

That soils low in lime will not lose 3.57 pounds of lime for each pound of nitrogen leached is shown by data from South Carolina (page 162). Eighty-seven pounds of nitrogen leached out of the soil, and only 170 pounds of lime equivalent as calcium, magnesium, and potash was lost, which is equal to slightly less than 2 pounds of pure lime per pound of nitrogen lost.

The application of superphosphate in a rotation including legumes has been reported to decrease the supply of lime in the soil. The decrease in the supply of lime is attributed to an increase in loss of bases as nitrates, due to increased legume growth from which more nitrogen was leached out of the soil.

The effect of continuous growth of soybeans and of turning them under on the yield of soybeans on Norfolk sand (1) is shown by the following data from South Carolina:

Fertilizer treatment	Yield of soybean hay—pounds per acre					
	1928	1929	1930	1931	1932	1933
No fertilizer......	2,556	1,156	194	300	74	310
400 lbs. 0-15-0....	5,158	2,110	972	1,040	1,072	940
400 lbs. 0-12-3....	5,158	2,580	1,224	1,600	2,472	2,620
400 lbs. 0-9-6.....	6,624	2,646	1,404	1,680	1,742	1,900

The data show that turning under soybeans continuously without fertilizer on Norfolk sand reduced the yield from 2,556 pounds per acre to 300 pounds or less in two years. With superphosphate the yields were reduced from 5,158 to 1,072 pounds or less after 2 years. Where 0-12-3 or 0-9-6 fertilizer was applied, the yields decreased considerably, but the 0-12-3 maintained higher yields. The above data were collected on a very sandy soil, and the decreases in yield took place much more rapidly than they would on most soils. The increased response to potash during the 6-year period suggests that the nitrate nitrogen leached potash out of the soil. However, other bases were also leached out as shown by the lowering of the pH.

Turning under the whole soybean crop or the leaves and straw as green manure lowered the pH of the above soil (1) up to 1 pH unit:

Fertilizer treatment	Decrease in pH after 6 years of soybeans		
	Seed only harvested	Green manure	Hay removed
No fertilizer.............	0.16	0.65	0.52
400 lbs. 0-15-0...........	0.94	0.90	0.56
400 lbs. 0-12-3...........	1.11	0.91	0.14
400 lbs. 0-9-6...........	0.59	0.57	0.47

The pH of the original soil was 5.0 to 5.5. The removal of hay also lowered the pH, but usually not to as great an extent as green manure, or leaves and straw. The hay which was harvested contained basic elements, the removal of which would tend to lower the pH of the soil. It should be borne in mind that these results were obtained on a very sandy soil, and that changes are produced much more rapidly on sandy soils than on soils which contain more clay.

The addition of nitrogen to the soil through legumes should have practically the same effect on the soil as the application of ammonium nitrate or urea. In soils well supplied with bases, the unharvested nitrogen in both cases is eventually converted into nitrate nitrogen, which is leached out of the soil largely as calcium nitrate, magnesium nitrate, and potassium nitrate. No element is added with legume nitrogen nor with urea and ammonium nitrate to increase or decrease the effects of the leaching of the nitrogen as nitrate. However, it takes 2 to 3 times as much nitrogen in legumes as in urea or ammonium nitrate to produce equal yields of crops, which suggests that much greater quantities of nitrogen and bases will be leached where legumes are used than where ammonium nitrate or urea is used as the source of nitrogen for crop production.

SUMMARY AND CONCLUSIONS

The nodule bacteria on the roots of legumes take nitrogen out of the air, which is stored in the form of protein throughout the plant. When legumes are turned into the soil, decomposition takes place, and the protein nitrogen is converted into ammonia nitrogen and in turn into nitrate nitrogen. Part of the ammonia or nitrate nitrogen is used by plants and returned to the soil in crop residues. Most of the nitrogen which is not removed in the harvested part of crops is eventually lost from soils as calcium nitrate, magnesium nitrate, and potassium nitrate. In the South, not more than 10% of the nitrogen

supplied by legumes would be expected to be present in the harvested crop; most of the other 90% probably leaches out of the soil in the nitrate form.

The data presented on the effect of leguminous green manures on the soil suggest:

1. That leguminous green manures deplete the soil of calcium, magnesium, and potash by the unharvested nitrogen leaching them out of the soil as nitrates.
2. The greater solubility of calcium and magnesium nitrates as compared to potassium nitrate suggests that little potassium will be lost from well limed soils.
3. The value of the potash lost with one pound of nitrogen as potassium nitrate is about 20 times as much as the value of the calcium and magnesium where one pound of nitrogen is lost as calcium and magnesium nitrates.
4. Continued success with leguminous green manure crops in humid climates can be expected only where soils are limed.

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(8)

The Effect of Harvesting Nitrogen, Phosphorus, Potash and Other Elements in Crops on the Yield of Crops Which Follow

Potash is the most deficient element where hay crops occupy the land for a large part of the time.

When this country was first settled, farmers cleared land and cultivated it until the yield declined to the point where it was profitable to clear new land. They cleared new land each year, and turned old land out to rest. When land became so limited that new land could not be brought into cultivation to replace worn-out land, crops were grown year after year on the same land. Farmers observed that corn for grain and cotton could be grown year after year with almost constant yields after the rapid decline soon after bringing land into cultivation.

With hay crops, the experiences of farmers have been variable. On soils which have a good supply of phosphorus and potash, the growth of leguminous hay crops increases the nitrogen content of the soil and the yield of the following crops. On soils which are low in phosphorus and potash, the growth of hay crops reduces the amount of phosphorus and potash in the soil, and poor crops are produced following the hay crops. Some of the expressions of farmers concerning the effects of hay crops on soils low in phosphorus or potash are as follows: "Several years of crab grass hay will ruin land"; "The quickest way to ruin land is to put it in alfalfa"; "Where alternate rows of corn and velvet beans are grown, the corn row makes more cotton than the velvet bean row the following year"; "Peanuts ruin land"; "Sweet

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potatoes ruin land"; "Lime makes the father rich and the son poor", "My soil is clover or legume sick"; "Oats ruin land"; "I ruined my land trying to grow cowpeas to build it up"; "Corn won't grow after several years of lespedeza hay"; "Sorghum ruins land"; "Tobacco will wear land out".

Where farmers have obtained unsatisfactory results from cropping systems involving hay or similar crops, it is due to (a) the removal of elements necessary for growth in the harvested crops, or to (b) the addition of organic matter low in nitrogen to the soil. The removal of elements necessary for growth is taken up in this chapter; the effect of the addition of organic matter low in nitrogen is taken up in Chapter 9.

Unfavorable results from the use of certain cropping practices show up more quickly on soils of low fertility. In many cases unfavorable results from the growth of soil-depleting crops have not yet shown up, due to the presence of a good supply of nutrients in the soil; ultimately, the removal of elements necessary for plant growth in harvested crops will deplete fertile soils just as it has depleted poor soils.

Different crops affect the fertility of the soil differently because they remove different amounts of nitrogen, phosphorus, potash and other elements. The fertilizing elements (4, 13)[1] contained in the harvested part of the average yield of different crops are listed in Table 1. The data may be used to calculate the nitrogen, phosphorus, and potash harvested with different yields per acre. The nitrogen, phosphorus, and potash removed in harvested crops are listed as nitrogen, phosphate (phosphoric acid) and potash because these elements are bought in fertilizers as nitrogen, phosphate, and potash. Considerable quantities of calcium and magnesium are removed in crops, but they are very cheap, and their removal in crops is of little economic importance.

Nitrogen stays in the soil from one year to the next in organic matter. The nitrogen in well-drained soils, which becomes available during the growth of one crop, is largely lost by leaching before the next crop is grown if it is not used by plants. The removal of soil nitrogen in harvested crops is, therefore, not a direct loss to the farmer; consequently, no value should be placed on the nitrogen removed in crops. In fact, the removal of nitrogen by crops may be advantageous because nitrogen which leaches out of the soil carries calcium, magnesium, and potash out in the drainage water.

The two fertilizing elements removed in harvested crops about

[1]Numbers in parenthesis refer to the source of information, page 187.

Table 1.—THE NITROGEN, PHOSPHORUS, AND POTASH CONTAINED IN CROPS, AND THE AMOUNTS HARVESTED PER ACRE.

Crop	Part of crop	Yield per acre	Nitrogen	Phosphoric acid	Potash
			Pounds	Pounds	Pounds
Cotton..........	Lint.............	200 lbs.	..	..	1
	Seed.............	360 lbs.	14	6	5
	Stalks, etc........	600 lbs.	10	3	14
	Total harvested.		14	6	6
Corn............	Grain............	25 bus.	24	14	7
	Stover...........	1,667 lbs.	16	6	15
	Grain............	15 bus.	14	8	4
	Stover...........	1,000 lbs.	11	3	9
Tobacco.........	Leaves...........	1,000 lbs.	37	7	57
	Stalks...........	800 lbs.	17	7	23
	Total harvested.		54	14	80
Wheat..........	Grain............	15 bus.	18	8	5
	Straw...........	1,250 lbs.	7	2	13
	Total harvested.		25	10	18
Oats............	Grain............	30 bus.	21	8	6
	Straw...........	1,500 lbs.	9	4	27
	Total harvested.		30	12	33
Barley..........	Grain............	24 bus.	21	11	8
	Straw...........	1,200 lbs.	9	3	21
	Total harvested.		30	14	29
Potatoes.........	Potato..........	200 bus.	43	17	77
	Tops.............	.....	40	7	37
	Total harvested.		43	17	77
Sweet potatoes...	Potato..........	200 bus.	30	10	50
	Vines...........	.....	20	3	27
	Total harvested.		30	10	50
Sugar beets......	Beet............	10 tons	37	15	35
	Tops............	.....	40	16	62
	Total harvested.		37	15	35
Tomatoes........	Fruit............	6 tons	36	12	48
	Vine............	.....	24	9	57
	Total harvested.		36	12	48

Table 1.—Continued.

Crop	Part of crop	Yield per acre	Nitrogen	Phosphoric acid	Potash
			Pounds	Pounds	Pounds
Cabbage.........	All...............	15 tons	100	25	100
Celery..........	All...............	350 crates	80	65	235
Spinach.........	All...............	9 tons	90	30	45
Apples..........	Fruit.............	400 bus.	20	7	30
Peaches.........	Fruit.............	500 bus.	30	15	55
Grapes..........	Fruit.............	4 tons	10	6	20
Oranges.........	Fruit.............	600 boxes	65	23	105
Soybeans........	Hay..............	1 ton	50	12	30
Soybeans........	Seed.............	15 bus.	66	16	20
Soybeans........	Vines............	1,500 lbs.	9	3	12
Peanuts.........	Nuts.............	1,000 lbs.	30	5	5
	Vines............	2,000 lbs.	40	12	51
	Total harvested.		70	17	56
Pea beans.......	Grain............	20 bus.	49	15	16
	Straw............	.....	14	5	21
	Total harvested.		63	20	37
Alfalfa..........	Hay..............	2 tons	93	25	107
Sweet clover.....	Hay..............	2 tons	74	18	60
Red clover.......	Hay..............	1½ tons	65	15	53
Lespedeza.......	Hay..............	1½ tons	65	15	35
Timothy........	Hay..............	1 ton	27	11	41
Cowpeas........	Hay..............	1 ton	63	15	67

which there is the greatest concern are phosphorus and potash. Phosphorus and potash are removed in crops in considerable quantities. They are expensive; and the percentage of the phosphorus and potash applied in fertilizers which is recovered in crops is low; consequently, the amounts necessary to add to maintain crop yields are considerably greater than the amounts removed in the harvested crops. Phosphorus stays in the soil from one year to the next; it is lost from the soil primarily in harvested crops. However, a small amount of phosphorus leaches out of the soil. Most of the phosphorus applied to soils is changed to slightly available forms. Potash is held in the soil as potash clay. Small amounts of potash leach out of the soil when water leaches through it. The acid elements applied in fertilizers increase the loss of potash by leaching. The clay holds potash sufficiently well that sandy loam soil may contain sufficient potash to grow good crops in which little potash is removed in the harvested part of the crop.

Cotton probably takes less phosphorus and potash out of the soil

than any other crop of importance. The average yield of cotton in the United States is approximately 200 pounds of lint and 360 pounds of seed per acre. The lint contains only one pound of potash and a negligible quantity of other fertilizing elements; the seed and lint contain 6 pounds of phosphate and 6 pounds of potash. As was pointed out above, most of the nitrogen removed in seed cotton would probably have leached out of the soil before the following crop was grown if it had not been removed in the harvested crop. The low amounts of phosphorus and potash removed in the harvested lint and seed suggests that cotton does not deplete the soil of its fertility rapidly. Farmers have found that cotton can be grown continuously without the yield declining seriously. Where soils are well supplied with phosphorus and potash, it appears that the minerals in the soil would give up these elements in as large quantities as they are removed by cotton where it is grown continuously. The phosphorus and potash in cotton stalks and leaves are returned to the soil. From the standpoint of the plant nutrients removed from the soil, cotton will probably deplete the soil more slowly than any other crop grown. These data support the general practice of farmers of growing cotton continuously on the best cotton land where it is the main cash crop.

After cotton, corn for grain takes less phosphorus and potash out of the soil than any other crop. The average yield of corn in the United States is 25 bushels per acre, which contains only 14 pounds of phosphate and 7 pounds of potash per acre. The South produces an average of about 15 bushels of corn per acre; 15 bushels of corn contain only 8 pounds of phosphate and 4 pounds of potash. Corn for grain reduces the phosphate and potash supply of the soil slowly. Where both the corn and stover are harvested, the average crop contains 20 pounds of phosphate and 22 pounds of potash. The growth of corn for silage depletes the soil of potash more rapidly than harvesting ear corn and stover, because part of the potash is leached out of the stover before it is removed from the field.

Oats, wheat, and barley each remove about 8 pounds of phosphate and 6 pounds of potash in the average crop when only the grain is harvested. When the straw is harvested also, an average of 10 pounds of phosphate and 18 pounds of potash is removed by wheat, 12 pounds of phosphate and 33 pounds of potash by oats, and 14 pounds of phosphate and 29 pounds of potash by barley. Where grain only is harvested, these crops deplete the soil of phosphate and potash slowly, but where the straw is harvested also, the depletion of potash and phosphate is much more rapid. **If cotton, corn, oats, wheat, and barley**

were grown on land of equal fertility, and if the straw and stalks were returned to the land, all of these crops would deplete the phosphorus and potash content of the soil slowly, and there would probably not be a measurable difference between them.

Tobacco depletes the potash supply of the soil very rapidly. A yield of tobacco of 1,000 pounds of leaves and 800 pounds of stems contains 14 pounds of phosphate and 80 pounds of potash which are removed from the soil.

Sweet potatoes and white potatoes remove large quantities of potash and thereby deplete the soil of its potash supply rapidly. A 200 bushel crop of sweet potatoes contains 50 pounds of potash, and the same yield of white potatoes contains 77 pounds of potash.

Vegetable crops usually contain large quantities of phosphate and potash which are harvested.

Hay crops contain from 25 to 65 pounds of potash, and from 10 to 20 pounds of phosphate per ton. Since 2 to 3 tons of hay are often produced per acre, hay crops deplete the phosphate and potash supply of the soil rapidly. The high amounts of phosphorus and potash removed in hay crops is largely responsible for the depletion of the soil by these crops, as observed by farmers.

In a long-time rotation in Illinois without treatment, the yield of hay was 2.0 tons per acre from 1888 to 1903, and only 1.4 tons per
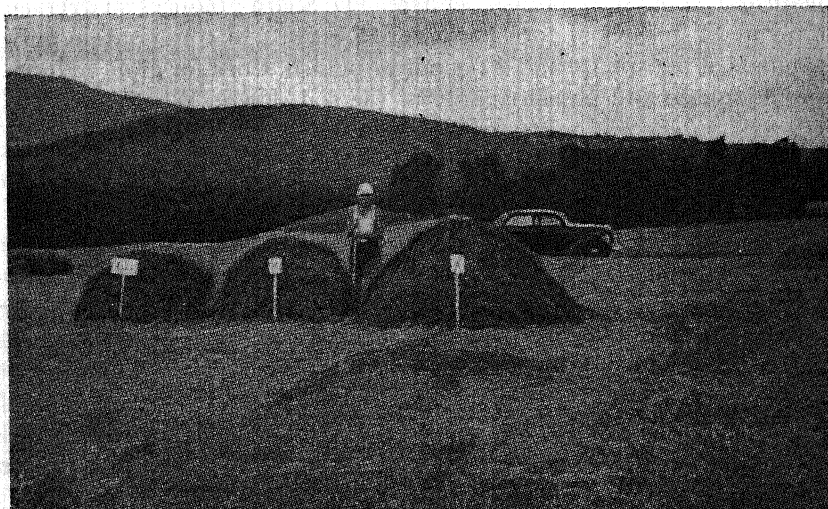
Fig. 1.—All hay producing areas will eventually use large quantities of phosphorus and potash. Left no treatment; center phosphorus; right potash (10).

acre from 1904 to 1926. The decrease in the yield of hay was probably due to the removal of plant nutrients in the hay and other harvested crops (see page 125).

The application of lime and phosphate in Kentucky (16) increased the yield of corn, wheat, and lespedeza in rotation, and reduced the amount of available potash in the soil. The check plots contained nearly twice as much available potash as the plots receiving phosphate or lime and phosphate. The crops on the check plots contained 20% more potash on a percentage basis than the crops on plots receiving phosphate or phosphate and lime. The reduced amount of available potash where lime and phosphate were used was due to the removal of more potash in the higher yields of crops produced.

That the potash removed in crops may be returned in manure is shown by data (15) from Kentucky (Table 2). The test was started in

Table 2.—RETURN OF POTASH IN MANURE.

Previous manure treatment	Yield of corn—1939—bushels		
	No potash	Potash	Increase for potash
None...................	38.3	48.1	9.8
4 tons..................	47.8	53.0	5.2
6 tons..................	51.4	54.2	2.8
8 tons..................	56.8	57.6	0.8

1920 on land which produced 75 bushels of corn per acre in good season without the use of manure. The rotation was corn, wheat, and clover, and 0,4,6 and 8 tons of manure was applied every three years. The use of manure was discontinued, and 200 pounds of muriate of potash was applied to half of each plot in 1939. Potash increased the yield of corn 10,5,3, and 1 bushel where 0,4,6, and 8 tons of manure was applied per acre, respectively. The plant nutrients removed in crops can be returned in manure, but the experience of American farmers is that it is not generally practicable to save a large percentage of the manure produced. A system in which cattle drop the manure on the land on which forage crops are produced may be the most efficient way of returning the plant nutrients to the soil.

The failure of clovers and other legumes after several years of continuous growth has been generally designated as "clover sickness." The removal of legume hays reduced the available plant nutrients to such a low level that old plantings died out and new plantings could

not be established. In recent years, clover sickness has disappeared in the Northeast where more lime, phosphorus, and potash have been used (9).

Cotton had a high potash requirement after lespedeza hay in tests conducted in Alabama (12). In one test after lespedeza hay, potash increased the yield 590 pounds of seed cotton per acre, and phosphate increased the yield 466 pounds per acre. In 5 tests the average yield was increased 356 pounds per acre by potash following lespedeza for hay.

Corn following lespedeza hay gave good increases in yield for the application of phosphate, potash, and a mixture of rare elements in one test (Table 3) in Alabama (12). The increase in yield was: for potash 5.7 bushels, for phosphate 7.1 bushels, for rare elements 8.5 bushels.

Table 3.—THE RESPONSE OF CORN TO FERTILIZERS FOLLOWING LESPEDEZA HAY

Fertilizer treatment, per acre	Bushels of corn per acre	
	Yield	*Increase*
No fertilizer	20.1	....
600 lbs. 0-8-0	27.2	7.1
600 lbs. 0-8-5	30.8	10.7
600 lbs. 0-0-5 plus 150 lbs. muriate of potash	30.8	10.7
600 lbs. 0-8-5 plus 150 lbs. muriate of potash	32.9	12.8
600 lbs. 0-8-5 plus 350 lbs. nitrate of soda	32.5	12.4
600 lbs. 0-8-5 plus minor elements	39.3	19.2

As an average of 4 similar tests phosphorus increased the yield 6.4 bushels of corn, and potash increased the yield 4.3 bushels per acre. These data suggest that deficiencies of plant nutrients are likely to be pronounced after hay crops.

The effect of harvesting vetch for hay as compared to turning it under for green manure on the yield of vetch and cotton is shown by the data[1] reported in Table 4. The data are for 5 years. The removal of vetch for hay reduced the yield of vetch slightly after the second year; however, the removal of the vetch for hay did not markedly reduce the yield of the vetch on any year.

In the case of cotton, marked reductions in the yield were obtained where the vetch was removed for hay, which was more marked where the fertilizer was applied to the vetch rather than to the cotton.

[1]Unpublished data of J. L. Anthony. Miss. Agr. Exp. Sta.

FIG. 2.—Phosphate is essential in rotations including legumes and stable manure (17). (Courtesy Indiana Agricultural Experiment Station.)

Treatment	Yield per acre—bu. corn.
Lime alone..	50
Lime and manure..................................	71
Lime, manure, and phosphate.....................	89

Table 4.—THE EFFECT OF HARVESTING VETCH FOR HAY ON THE YIELD OF VETCH AND COTTON.

Plot No.	500 lbs. 0-8-4 applied to	Disposition of vetch	Year					
			1940	1942	1943	1944	1945	Average
			Pounds of green vetch per acre					
1	Vetch.....	Hay......	1,920	7,944	9,600	5,248	3,680	5,678
2	Vetch.....	Green manure....	1,920	8,348	10,000	6,016	5,024	6,262
3	Cotton....	Hay......	1,156	3,172	7,680	4,128	3,296	3,886
4	Cotton....	Green manure....	1,064	4,880	7,840	4,992	3,120	4,379
			Pounds of seed cotton per acre					
1	Vetch.....	Hay......	276	1,128	864	944	1,040	850
2	Vetch.....	Green manure....	272	1,280	936	1,448	1,771	1,141
3	Cotton....	Hay......	354	1,132	1,048	1,306	1,394	1,046
4	Cotton....	Green manure....	332	1,328	1,080	1,564	1,856	1,232
7	500 lbs. 6-8-4 applied to cotton............		524	1,300	1,080	1,728	1,888	1,304

In 1944 the plots were divided, and 100 lbs. of extra muriate of potash was added to half of each plot. The yields are reported in

Table 5.—THE EFFECT OF HARVESTING VETCH AS HAY ON THE RESPONSE OF THE FOLLOWING COTTON CROP TO POTASH.

Plot No.	500 lbs. 0-8-4 applied to	Disposition of vetch	Treatment with extra potash	
			None	100 lbs. muriate of potash
			Yield—lbs. seed cotton per acre	
1	Vetch............	Hay..............	1,040	1,416
2	Vetch............	Green manure.......	1,771	1,931
3	Cotton..........	Hay..............	1,394	1,552
4	Cotton..........	Green manure.......	1,856	1,752
7	500 lbs. 6-8-4 applied to cotton..........		1,888	1,819

Table 5. Even though there is some inconsistency in the data, they show that more potash is needed where vetch is removed for hay than where it is used as a green manure. The response to potash was greater where 0-8-4 fertilizer was applied to the vetch than where it was applied to the cotton.

The effect of removing plant nutrients in harvested crops on the yield of crops which follow is illustrated by data (Table 6) from Alabama (1) where peanuts were grown. The 1939 yield of seed cotton was 1,269 pounds per acre after 7 years of fertilized cotton, and 1,201 pounds after unfertilized corn for grain and fertilized cotton on alternate years. Where peanuts were hogged-off, the 1939 yield of cotton without nitrogen was 1,174 pounds of seed cotton per acre. On this soil hogged-off peanuts supplied most of the nitrogen necessary for the following cotton crop; however, in other tests, it has been found

Table 6.—THE EFFECT OF HARVESTING PEANUTS ON THE YIELD OF THE FOLLOWING COTTON CROP.

	Yield—pounds seed cotton per acre in 1939
Cotton continuously 600 pounds 6-8-4........................	1,269
Cotton, 600 pounds 6-8-8 under cotton after 7 years of unfertilized harvested peanuts........................	345
Cotton, 600 pounds 0-8-4 under cotton, after 4 crops of hogged-off peanuts and 3 crops of cotton in alternate years.............	1,174
Cotton, 600 pounds 6-8-4 under cotton, after 4 crops of corn without fertilizer and 3 crops of fertilized cotton in alternate years.......	1,201
Cotton, 600 pounds 6-8-4, after 2 crops of fertilized cotton, 3 crops of unfertilized corn and 2 crops of unfertilized harvested peanuts...	652
Cotton, 600 pounds 6-8-12, in 1939, in corn, harvested peanut rotation as above........................	1,075

that hogged-off peanuts will not generally supply sufficient nitrogen for the following crop of cotton or corn. It should be pointed out that peanuts reduce the amount of nematodes in soils. On nematode infested land a rotation including peanuts will reduce the nematodes which attack crops like cotton.

Peanuts are heavy feeders on potash, and it is estimated that the dug peanuts removed from 40 to 50 pounds of potash per acre per year. That potash probably was not solely responsible for the decrease in yield of cotton produced by harvested peanuts is illustrated by the following deduction from the data:

> The yield of seed cotton with 600 pounds of 6-8-8 fertilizer (48 pounds potash) per acre was only 345 pounds per acre after 7 crops of harvested peanuts. With potash as the sole limiting factor in cotton production, and with a season where 1,200 pounds of seed cotton per acre was produced on other plots in the test, 48 pounds of potash should have increased the yield twice as much as the total yield actually obtained on this plot.

Without minimizing the beneficial effect of returning the phosphate and potash lost in the harvested peanuts to the soil, it appears that some other element was partly responsible for the decrease in yield obtained.

High amounts of potash are required by cotton after harvested peanuts. In 5 tests in North Carolina (2) 600 pounds of 6-8-8[1] fertilizer made 130 pounds per acre more seed cotton than 600 pounds of 6-8-4 fertilizer. The data are 5-year averages. On one year the extra potash increased the yield 525 pounds of seed cotton per acre in one test. These data show that harvested peanuts increase the requirement of crops which follow for potash.

The fertilizer requirement of cotton after two years of oats and vetch for hay followed by sorghum for silage in the summer is shown by unpublished data from Mississippi (Table 7). A system of oats and vetch for hay in the winter and early spring and sorghum for silage in the summer and fall depletes the soil of phosphorus and potash and other elements as rapidly as almost any cropping system. After two years of this system of cropping, cotton was grown for five years.

During the first three years of the test potash trebled the yield of cotton. On the fourth year, potash gave no significant increase in yield. On the fifth year potash again made large increases in the yield of

[1]6-12-6 and 6-12-12 in one test.

Table 7.—The Response of Cotton to Potash after Two Hay and Two Silage Crops.

Treatment	Yield in pounds of seed cotton per acre				
	1937	1938	1939	1940	1941
No fertilizer.....	230	225	404	717	417
600 lbs. 4-8-0....	531	405	614	1,112	600
600 lbs. 4-8-4....	881	1,170	1,243	1,252	1,068
600 lbs. 4-8-8....	1,112	1,571	1,683	1,129	1,251
600 lbs. 4-8-12...	1,184	1,706	1,813	1,077	1,299
600 lbs. 4-0-4....	567	873	1,115	1,158	1,092
600 lbs. 4-4-4....	725	986	1,224	1,128	990
600 lbs. 4-12-4...	878	1,013	1,201	1,223	1,092
600 lbs. 0-8-4....	770	972	1,206	1,210	1,005
600 lbs. 6-8-4....	954	1,247	1,370	1,162	963
600 lbs. 8-8-4....	945	1,170	1,377	1,116	968

cotton. Austrian winter peas were grown in the winter and turned under for cotton. Phosphate increased the yield over 300 pounds of seed cotton the first year of the test. The winter peas received basic slag, which may have been responsible for the response to phosphate declining over the 5-year period.

The response of cotton to potash after several years of corn, small grain, and hay is shown by data (7) in Table 8 from South Carolina. Prior to the time the test was begun, the crops had not received a complete fertilizer annually, which probably means that no potash had been used. When the straw of small grains is removed in a rotation with hay crops, the potash supply of the soil is depleted rapidly. After this system of cropping, cotton made a very low yield without potash, and 75 pounds of potash was required for maximum yield. The potash required for maximum cotton yield was five times the amount removed in the harvested cotton.

Table 8.—The Response of Cotton to Potash After Several Years of a Rotation Including Hay Crops.

Pounds of potash applied	Average yield of seed cotton Pounds per acre—1936-1939
0	176
15	522
30	1,037
45	1,076
60	1,220
75	1,417
100	1,248

Even though the removal of phosphorus and potash particularly should receive major consideration where the whole plant is removed from the soil, other elements must be given consideration. A deficiency of boron often occurs on soils on which high yields of harvested crops are grown. Beets, turnips, cabbage, apples, and alfalfa often respond to boron. A maximum yield of 5 tons of alfalfa per acre for 5 years contains about 1.7 pounds of boron. A normal application of 10 pounds of borax per acre contains slightly more than one pound of boron. Potato and sweet potato leaves are high in boron (8). The leguminous hays are quite high in boron (8). It is significant that most cases of rare element deficiencies have occurred where hay crops, truck crops, sugar beets and other crops are grown and most of the plant is harvested.

The value of corn stalks in Indiana (11) was found to be $1.78 per acre when they were burned and the ashes returned to the soil, and $3.36 per acre when they were disked and plowed under over a 10-year period. The higher value for corn stalks than for ashes is probably due to the loss of nitrogen where the stalks were burned. With soils low in potash, the value of corn stalks may be considerably greater. It appears that the value of corn stalks is largely lost when they are raked and burned, due to the concentration of the ash in a small area.

The application of 2 tons of corn stalks or the ashes from 2 tons of stalks in a 4-year rotation in Illinois (18) produced equal yields of clover and soybeans, but corn produced 1.3 bushels more and wheat 1.6 bushels more where the stalks were turned under than where only the ashes were scattered over the land. However, these differences in yield are not significant. A recent publication from Illinois (3) bears out the data on the loss of fertilizing elements in harvested crops as follows:

1. The response of crops to rock phosphate is much greater in a system of farming where grain is sold and the straw removed from the land than in a livestock system where the plant nutrients removed are returned in manure. The amount of manure applied in these tests was larger than most farmers can use economically.

2. The 1935-1938 response to potash was much greater than the 1910-1938 response in the grain system of farming.

The effect of phosphate on the yield of wheat after soybeans for hay as compared to sweet clover turned under is illustrated by data (14) (1 year) from Illinois in Figure 3. One ton of soybean hay contains 12 pounds of phosphate; a yield of two tons of soybean hay would contain 24 pounds of phosphate. The response to phosphate after soybean hay was unusually high. The data illustrate the effect of har-

WHEAT YIELDS WITH AND WITHOUT PHOSPHATE FERTILIZATION		
		BUSHELS PER ACRE
AFTER SWEET CLOVER NO PHOSPHATE ADDED	30.2	
PHOSPHATE ADDED	30.3	
AFTER SOYBEANS NO PHOSPHATE ADDED	21.8	
PHOSPHATE ADDED	30.3	
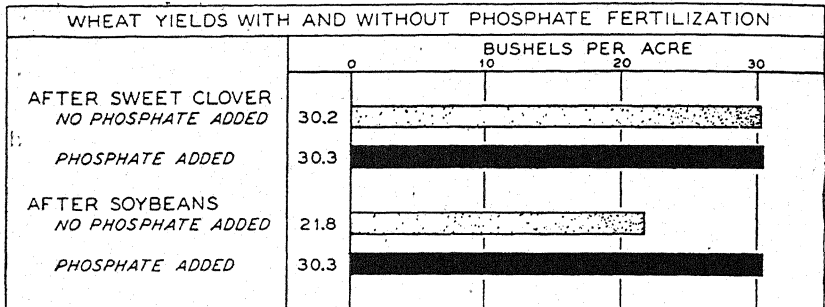
FIG. 3.—Soybeans cut for seed removed needed phosphorus (14).

vesting hay crops on the available phosphorus in the soil; however, the deficiency produced may be greater than would occur on most soils. Apparently, the removal of phosphorus in the soybeans reduced the yield of wheat 8.5 bushels per acre.

Harvesting soybeans for hay reduced the yield of the following corn crop 17 bushels per acre over an eleven-year period as compared to harvesting the seed only, in North Carolina (6). Corn and soybeans received a complete fertilizer in a 2-year rotation over the eleven-year period. The yield of corn was 56 bushels per acre where the soybeans were harvested for seed and 39 bushels per acre where they were harvested for hay (Figure 4).

Hay crops are grown for enterprises which necessitate valuing

FIG. 4.—Corn responded to potash after soybean hay in a two-year rotation. The corn on the left received nitrogen, phosphorus, and potash; that on right received nitrogen and phosphorus (6).

hay at a low price per ton. Where hay crops contain 12 pounds of phosphate and 30 pounds of potash per ton, it probably will require 300 pounds of 20% superphosphate and 120 pounds of muriate of potash to maintain the yield where one ton of hay is produced annually. These fertilizers cost approximately $5.00. Where hay crops are harvested and fed to animals at the barn, only a small part of the phosphorus and potash is returned to the soil from which they came in the form of manure.

There are six possibilities concerning the future of a livestock system of farming:

1. It may be assumed that the soils have sufficient phosphorus and potash and other elements to produce hay crops continuously, and that one can stay in livestock production where only a small part of the plant nutrients removed in crops is returned in manure. This assumption will lead to a depletion of the soil and a bankrupt farmer.

2. The land may be used for hay crops until it is depleted, abandoned, and new lands sought. There are no frontiers, except in South America.

3. Fertilizers can be bought to replace the elements removed in hay crops. This system will work where market milk is sold for a high price. Beef cattle, and dairying for condenseries, cheese plants, and creameries do not produce sufficient income with the normal prices to pay the cost of this system. If the price of livestock products were doubled, this system would be profitable.

4. Feeder cattle may be bought and grazed for one season and sold grass fat. The cost of maintaining the land under this system is small.

5. The solid and liquid manure may be saved carefully and returned to the soil. This system has worked in successful dairy countries of Europe. The cost of labor in this country may make the system prohibitive.

6. The hay crops may be stacked and fed on the land from which they were removed. With normal prices this system appears to be the only system which will stand up for beef cattle and for dairying for condenseries, cheese plants, and creameries.

Wintering beef cattle on pasture clippings stacked and fed in the pasture has been successful in Mississippi. With this system the plant nutrients in the manure are returned directly to the soil from which they came, and the large losses which result from feeding forages at barns are avoided. The yield of hay produced on ungrazed pasture land has compared favorably with yields on land devoted to cultivated hay crops. In fact, due to the longer growing season for pasture plants,

considerably greater yields should be produced on pasture land than on cultivated hay land. This system may offer more soil conservation possibilities than any system which has yet been put into general use. If the cost of land preparation and seed for hay crops were invested in fertilizers and applied to pastures for hay, the yield of hay might be considerably larger than is obtained from the usual hay crops.
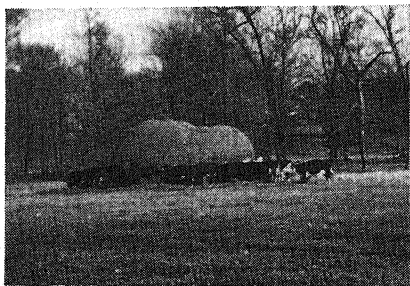
FIG. 5.—A method for returning most of the nutrients harvested in hay crops to the soil from which they came. (Courtesy Mississippi Agricultural Experiment Station.)

Marketing farm crops as livestock and livestock products leaves most of the plant nutrients on the farm. To produce a 1,000-pound steer requires approximately 5,000 pounds of hay and 15,000 pounds of pasture plants. Assuming that the forage necessary to produce the 1,000-pound steer has the same plant nutrients as lespedeza hay, it contains 433 pounds of nitrogen, 100 pounds of phosphate, and 265 pounds of potash; the steer contains about 30 pounds of nitrogen, 18 pounds of phosphate, and 2 pounds of potash. From the standpoint of maintaining soil fertility, little is lost where livestock and livestock products are marketed where the manure is handled wisely, but much is lost where forage crops are removed and the manure fails to get back to the land from which the forage is harvested.

SUMMARY AND CONCLUSIONS

Data were presented on the plant nutrients removed in crops. Where the seed only is harvested the plant nutrients removed are relatively insignificant; however, where the whole plant is harvested, the loss of nutrients is of considerable importance and may be reflected in the yield of crops which follow.

In humid climates nitrogen which becomes available during the growth of a crop is largely lost from well-drained soils before the next crop is grown; its removal in harvested crops is, therefore, not considered a loss. The value of the calcium and magnesium removed in

harvested crops is relatively low. The amount of lime necessary to apply to soils is only slightly affected by the calcium and magnesium removed in crops. It, therefore, does not appear necessary to evaluate the calcium and magnesium removed in harvested crops.

The two elements removed in harvested crops about which there is greatest concern are phosphorus and potash. The percentage of these plant nutrients applied in fertilizers which is recovered in crops is relatively low, and the cost of replacement is high.

The data on the effect of harvesting nitrogen, phosphorus, potash and other elements in crops on the soil show that:

1. Crops like cotton, and grain crops from which grain only is harvested, take little phosphorus and potash out of the soil.
2. Hay crops and other crops, the leaves and stalks of which are harvested, remove large amounts of phosphorus and potash from the soil.
3. Cash crops which remove only small amounts of phosphorus and potash from the soil should not be rotated with less valuable hay crops which remove large amounts of these elements.
4. Where hay crops are fed on the land on which they are produced the loss of plant nutrients is low.
5. When hay is produced and fed on permanent pastures, or a rotational grazing and feeding scheme is established which will keep the fertilizing elements harvested in forage crops evenly distributed over the farm the loss of plant nutrients is low.
6. The nitrogen removed in harvested crops is probably not a loss, because the available nitrogen which is not used by plants leaches out of the soil in humid climates before the next crop year.
7. The cost of maintaining the phosphorus and potash supply of soils devoted to hay, after the supply has been reduced to the point where both are deficient, is estimated to be about $5.00 per ton of hay. The cost may be greater where cowpeas, alfalfa, and other legumes high in potash are grown.
8. Marketing farm crops as livestock removes much smaller quantities of plant nutrients from the soil than marketing the crops as such.

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(9)

Soil Organic Matter

Only sod crops build up the organic matter in soils to a higher level.

That soils high in organic matter are more productive than soils low in organic matter has been recognized since the cultivation of land began. Early people recognized the importance of organic matter in crop production, and one of their theories concerning plant growth was that plants use partly decomposed organic matter for food. Now, it is generally recognized that the importance of organic matter for plant growth is due primarily to the fact that upon decomposition it gives up nitrogen, phosphorus, potash, calcium, magnesium, and other elements on which plants feed; and the most important of these is nitrogen, because it is most often deficient unless an effort is made to maintain it.

Before the introduction of commercial nitrogenous fertilizers, which have come into general use only in the last 50 to 60 years, the nitrogen which cultivated plants obtained came almost entirely from soil organic matter and animal manures; consequently, soil organic matter and animal manures came to be regarded highly by farmers. The introduction of commercial nitrogenous fertilizers has largely eliminated the necessity for using animal and green manures where crop residues are returned to the soil. That animal and green manures are not essential for the maintenance of high yields is shown by the fact that the most intensive farming areas in this country, which are along the Atlantic Coast, depend upon commercial nitrogen as well as other commercial fertilizers almost entirely for sustained high yields.

The return of organic matter to the soil increases:

1. Available nitrogen
2. Numbers of bacteria and fungi
3. Ease of plowing
4. Percolation of water
5. Water holding capacity, and
6. Reduces erosion.

All of the beneficial effects of organic matter are combined to increase crop yields. The total value of organic matter is, therefore, determined by the yield of crops produced by its application. The effect of organic matter on the ease of plowing may be of economic importance under certain conditions, but it is difficult to evaluate.

Soil organic matter contains approximately 5% nitrogen, and either nitrogen or organic matter is indicative of the amount of the other present. Multiplying the pounds of nitrogen in a soil by 20 gives the approximate amount of organic matter present; and dividing the
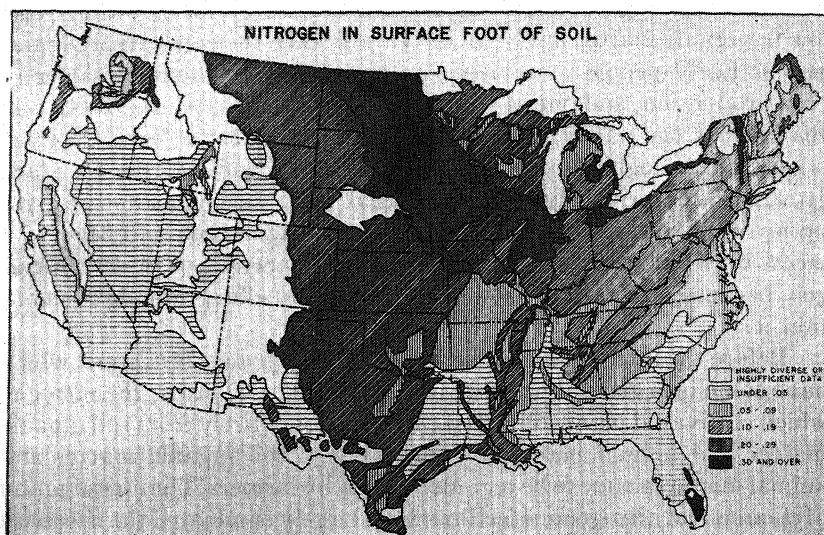
Fig. 1.—Soil nitrogen map of the United States. (Courtesy U. S. D. A.)

organic matter by 20 gives the approximate amount of nitrogen present. Organic matter is approximately 50% carbon. Soil organic matter contains 10 times as much carbon as nitrogen.

The average nitrogen content of the soils of the United States (14)[1] is shown in Figure 1. Since soils contain about 20 times as much organic matter as nitrogen, the map also indicates the relative amount of organic matter in the soils. In general, organic matter is higher where grass native vegetation was present than where forests were native. Nitrogen and organic matter are high where temperature is low and moisture is high.

The relation of temperature to the yield of corn (8) is shown by

[1]Numbers in parenthesis refer to the source of information, page 209.

data in Figure 2. Except north of central Iowa where lower tempera-
tures limit corn yields, the yield of corn and the quantity of nitrogen
in the soil decrease from north to south. High yields of corn are pro-
duced in Iowa where the nitrogen content of the soil is high, and low
yields are produced in the South where the nitrogen (and organic matter)
content of the soil is low. Most of the corn yields of over 200 bushels
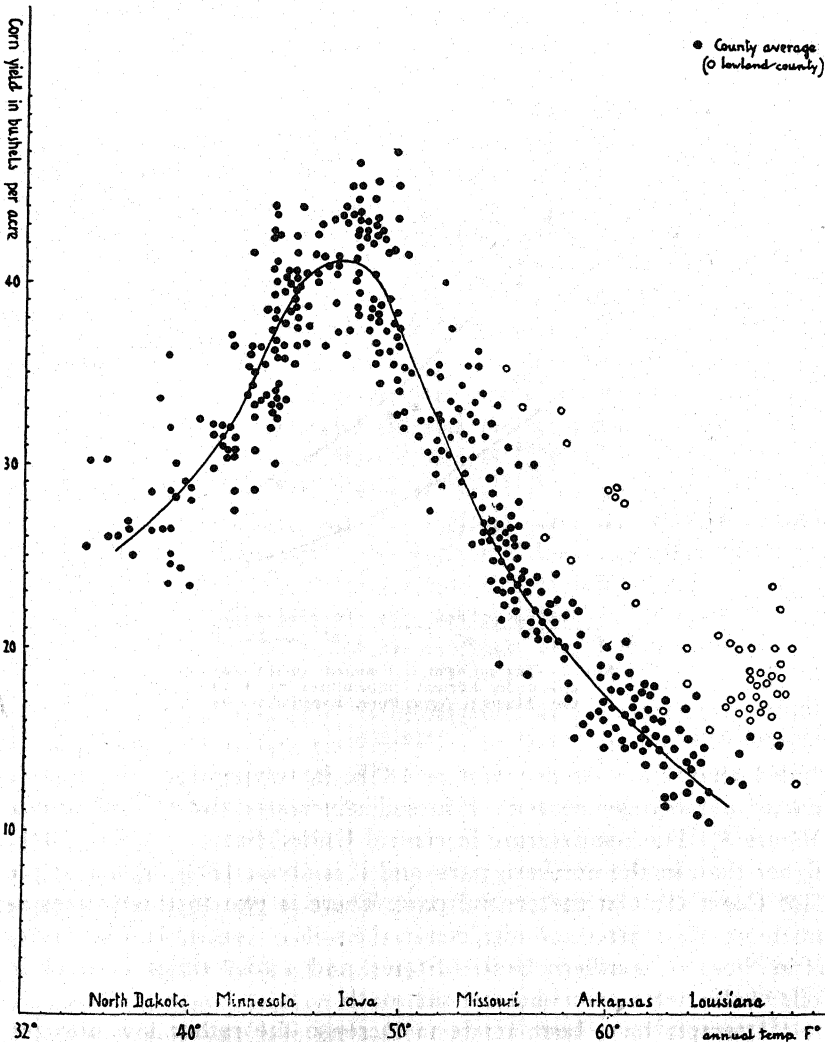
FIG. 2.—The relation of corn yields to temperature (8). (Courtesy Missouri Agricultural Ex-
periment Station.)

per acre have been produced in the South, which suggests that the climate in the South is as suitable for corn production as is that of Iowa. The record yields were obtained in the South on well-fertilized soils which have a high water table and which are naturally high in nitrogen. The difference in average yields of corn produced in the South and in the Middle West must be attributed to differences in fertility and to differences in the distribution of moisture.

Jenny (8) made a careful study of the relation of temperature to soil nitrogen and organic matter. With soil moisture constant, he con-
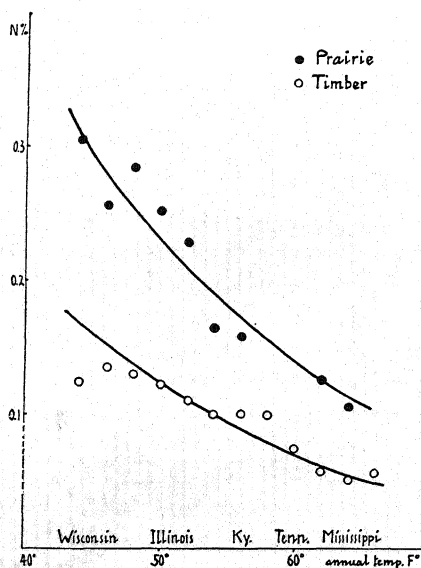
Fig. 3.—The nitrogen (N) content of silt loam soils under different temperatures (8). (Courtesy Missouri Agricultural Experiment Station.)

cluded that for each decrease of 18°F. in temperature the organic matter and nitrogen content of the soil is increased two to three times. (Figure 3). The temperature in central United States is about 18°F. higher than in the northern part, and it is about 18°F. higher at the Gulf Coast than in the central part. There is two to three times as much organic matter and nitrogen in the soils of central United States as in those of southern United States, and 4 to 9 times as much in soils of the north as in those of the south.

"Attempts have been made to increase the rather low nitrogen content of some of the Missouri soils by application of manure and

green manure in various schemes of rotation. Careful analyses show, however, that it has not been possible to build up soil nitrogen on a profitable basis. Even under rather large applications of nitrogen the increase is small" (8). The system of cropping establishes a rather definite level of nitrogen or organic matter in the soil, which is not altered significantly by green manures, stable manures, or commercial fertilizers so long as these are applied on an economical basis.

After studying the relation of climate to soil organic matter and nitrogen, Jenny (8) concluded that "crop production will probably be maintained or increased in the southern two-thirds of the United States, at least, by the application of nitrogen in commercial fertilizers, crop residues, green manures, and animal manures from crop to crop or rotation to rotation, rather than by an attempt to maintain the nitrogen content of the soil at a particularly high level."

The organic matter and nitrogen content of prairie soils, on which grass was growing before being brought into cultivation, is nearly twice as high as that of soils on which forest trees grew. (Figure 3). Probably the primary reason for the higher organic matter and nitrogen content of prairie soils is that many grasses die each year, leaving their roots in the soil where they decompose slowly. Most of the forest litter decomposes before it gets into the soil, and as a result forest soils do not have much organic matter, even though large yields of leaves fall on the land each year.

The relation between available moisture and the nitrogen content of the soil (8) is shown in Figure 4. Soils of low moisture content are low in organic matter and nitrogen, and soils high in moisture are high in soil organic matter and nitrogen. A high soil moisture content increases the production of plant material, and reduces its rate of decomposition.

With sufficient moisture, as in old lake beds, almost pure organic matter may accumulate to depths of 20 feet or more. The present beds of coal were derived from organic matter which accumulated in water. Soils developed in old lake beds or in wet places are high in organic matter, and they are called peat, muck, and reedbrake soils. The effect of moisture in reducing decomposition is borne out by the rotting of fence posts. Fence posts rot off at the surface of the ground while the part deeper down where more moisture exists may be sound. Also, the section of well curbing under water does not decompose rapidly; and it may outlast several sections which are not submerged.

The organic matter in the soil is decomposed by bacteria and fungi. The bacteria and fungi are very small plants. The rate of decomposition

of organic matter and growth and reproduction of bacteria and fungi
are dependent upon temperature and moisture. Another factor which
influences the decomposition of organic matter is the aeration of the
soil; however, soil aeration and moisture are so closely tied up that it
would be difficult to separate their contribution to the decomposition
or preservation of soil organic matter. Soils which are high in moisture
are poorly aerated; soils which are low in moisture are well aerated.
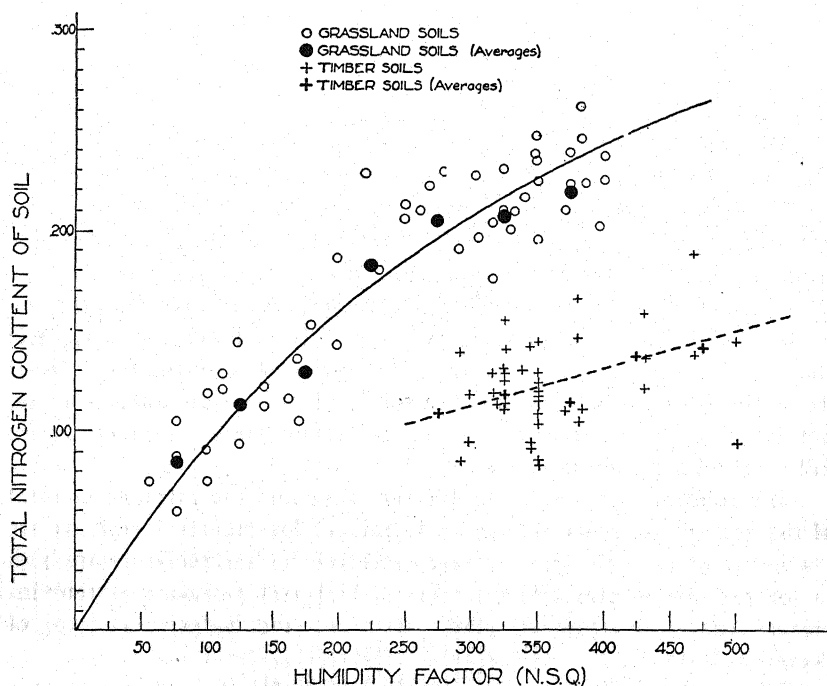
FIG. 4.—The effect of soil moisture on soil nitrogen (8). (Courtesy Missouri Agricultural Experiment
    Station.)

The effect of moisture and temperature upon the accumulation of
organic matter in the soil has been investigated over very large areas,
but no data have been reported on the moisture, temperature, aeration
and organic matter relations of soils on one farm. Clay soils have a
lower temperature, a higher moisture content, and less aeration than
sandy soils, all of which contribute to clay soils maintaining a higher
organic matter content than sandy soils.

  **Turning under stable manure and green manure is not essential
to the maintenance of high yields of crops over long periods of time.**

The yield of wheat was maintained at the same level where mineral fertilizers were used as where stable manure was applied for a 97-year period at Rothamsted, England, Experiment Station (7). The soil contained more organic matter and was in slightly better physical condition where stable manure was used. The equality of the yields with the two treatments suggests that the beneficial effect of the manure was due to the plant nutrients which it supplied to the wheat.

Grass vegetation increases the nitrogen (or organic matter) content of soils as is shown by data (Table 1) (13) from New York. The

Table 1.—THE EFFECT OF DIFFERENT CROPS ON SOIL ORGANIC MATTER.

Crop	Gain or loss of soil nitrogen—pounds per acre in 11 years
Grass without plowing......................	415 gain
Vetch plowed under.........................	42 loss
Rye plowed under.............	217 loss
Peas plowed under..........................	380 loss
Oats plowed under..........................	382 loss
Buckwheat plowed under...................	412 loss

growth of grass without plowing increased the nitrogen content of the soil 415 pounds per acre. The other crops were turned under and all reduced the nitrogen content of the soil. The above data were collected on a soil which was in alfalfa before the experiment was started, which would have caused the nitrogen content of the soil to be high at the beginning of the test. The data suggest that the organic matter content of cultivated soils can not be increased by green manure crops alone; they also show that devoting land to grass without cultivation increases organic matter. Green manure crops are easily and almost completely decomposed, and if increases in organic matter are obtained by their use, it may be due to increases in residues of other crops which decompose more slowly. If grain crops had have been used in a rotation with the above green manure crops, and the grain crop residues, which are more resistant to decomposition, had have been returned to the soil, a small increase in soil nitrogen (and organic matter) probably would have been obtained instead of a significant decrease.

The effect of a rotation of corn, oats, wheat, and timothy for 30 years as compared to the growth of weeds and grasses on the nitrogen and organic matter in soils (calculations made from New Jersey data) is shown (3) in Table 2. Weeds and grass, as compared to the rotation, doubled the nitrogen and organic matter content of the soil. The ap-

plication of nitrogen to the land on which weeds and grass grew increased the nitrogen content of the soil 560 pounds per acre, and the organic matter content 9,700 pounds per acre.

The corn, oats, wheat, and timothy were harvested, and the application of nitrogen did not increase the nitrogen or organic matter content of the soil as it probably would with crops like cotton and corn, where increased crop residues are returned to the soil. The increase in the nitrogen and organic matter content of soils growing weeds and

Table 2.—The Effect of Weeds and Grass and a Crop Rotation on the Organic Matter and Nitrogen Content of the Soil.

Treatment	Nitrogen			Organic matter		
	1913	1916	1937	1913	1916	1937
	Pounds per acre			Pounds per acre		
	Corn, oats, wheat and 2 years of timothy					
Phosphorus and potash.....	1,700	1,460	1,540	34,900	34,400	33,600
Nitrogen and potash........	1,720	1,620	1,620	37,800	36,800	33,300
Nitrogen and phosphorus...	1,680	1,620	1,400	34,400	33,800	29,800
Nitrogen, phosphorus and potash.................	1,680	1,660	1,600	35,700	36,600	33,600
Average of nitrogen treated plots..................	1,700	1,640	1,540	36,000	35,700	33,600
	Weeds and native grasses					
Phosphorus and potash.....	1,940	1,980	2,320	42,200	43,900	52,700
Nitrogen and potash........	1,980	2,040	3,100	43,900	45,000	65,700
Nitrogen and phosphorus...	2,140	2,120	2,920	46,600	47,700	63,700
Nitrogen, phosphorus and potash.................	2,160	2,140	2,640	45,600	46,000	58,500
Average of nitrogen treated plots..................	2,100	2,100	2,880	45,400	46,200	62,700

grass is not an argument for devoting land to weeds and grass; it is a reason for maintaining land in non-cultivated crops as much as possible without reducing the farm income. The ideal system where practicable would be to rotate non-cultivated grazing crops with cultivated land.

Weeds and grass increase the available lime, magnesium, and potash content of the soil (17), as well as the organic matter and nitrogen content (Table 3). The data were collected in New Jersey, where a rotation of cultivated crops was compared to weeds and grass. The lime and magnesium contents of the soil were doubled, and the

potash content was trebled by weeds and grass as compared to a rotation of cultivated crops.

The data on the beneficial effect of weeds and grass on the available plant nutrients suggest that rotations including long periods in which land is devoted to grazing crops which are not plowed will help to maintain high soil fertility.

Table 3.—THE EFFECT OF WEEDS AND GRASS ON THE ACCUMULATION OF LIME, MAGNESIUM AND POTASH IN THE SOIL (1913-1937).

Treatment	Rotation			Weeds and grass		
	Lime	Mag-nesium carbonate	Potash	Lime	Mag-nesium carbonate	Potash
	Pounds per acre					
Phosphorus and potash.........	2,870	424	244	5,430	704	723
Nitrogen and potash.........	1,800	416	188	4,950	688	723
Nitrogen and phosphorus.....	3,040	416	63	5,990	808	273
Nitrogen, phosphorus and potash.........	2,270	384	207	5,800	760	818

Turning under 2,308 pounds of dry soybean hay per acre each year as a green manure for 28 years in New Jersey (3) had no effect on the nitrogen and organic matter content of the soil where wheat was followed by soybeans for green manure. During the 28-year period approximately 65,000 pounds of dry soybean hay and 1,900 pounds of nitrogen were turned into the soil. Since such large amounts of green manure had no measurable effect on the organic matter in soil at the end of this period, these data also show that the organic matter content of cultivated soils can not be increased significantly with green manure crops.

The relation of total nitrogen in the soil to the yield of corn is shown by the data (10) in Table 4 from Missouri. The soils which contained the highest quantity of nitrogen produced the highest yield of corn, and the yields decreased regularly as the nitrogen content of the soil decreased. Under Missouri conditions, one bushel of corn was produced for each 100 pounds of nitrogen in the soil. Soils contain approximately 2,000 pounds of organic matter for each 100 pounds of nitrogen present.

Table 4.—The Relation of Soil Organic Matter to Corn Yield.

Soil type	Total nitrogen, pounds per acre 7 inches deep	Average yield of corn in bushels per acre
Marshall silt loam............	3,630	39
Grundy silt loam.............	3,370	32
Eldon silt loam..............	3,160	31
Crawford silt loam...........	2,840	25
Cherokee silt loam...........	1,950	23
Gerald silt loam.............	1,890	19
Union silt loam..............	1,600	16

Nitrogen may be substituted for soil organic matter. One hundred pounds of ammonium nitrate (annually), which contains 32 pounds of nitrogen, has the same corn producing value as 24,000 pounds of soil organic matter which contains 1,200 pounds of nitrogen. Either 32 pounds of nitrogen annually or an accumulation of 24,000 pounds of soil organic matter produces approximately 12 bushels of corn. However, it should be pointed out that crop residues are decomposed more easily than soil organic matter as a whole; consequently crop residues are much more valuable for crop production than soil organic matter which decomposes slowly.

Soils which have a high amount of nitrogen before being brought into cultivation (10) maintain a higher nitrogen content under cultivation than do soils which have a low amount of nitrogen before being brought into cultivation (Table 5). Soils which are high in organic matter before being brought into cultivation are also high in moisture

Table 5.—The Loss of Nitrogen in Soil Organic Matter in Different Soil Types.

Soil type	Nitrogen in surface 7 inches			Percentage loss in Nitrogen
	Virgin	Cultivated	Loss	
	Pounds per acre			
Marshall silt loam............	5,980	3,530	2,450	41
Grundy silt loam.............	5,200	3,340	1,860	36
Shelby loam.................	4,630	3,100	1,530	33
Summit silt loam............	4,590	3,520	1,070	23
Eldon silt loam..............	4,270	2,720	1,550	36
Putnam silt loam............	3,940	2,580	1,360	35
Baxter silt loam.............	3,020	1,820	1,200	40
Crawford gravelly loam........	2,580	1,640	940	36
Average....................	4,276	2,781	1,495	35

and nutrients necessary for crop production. Consequently, high crop yields are most often produced on soils which were high in organic matter and nitrogen before being brought into cultivation. Raising the nitrogen or organic matter content of cultivated soils originally low in nitrogen and organic matter to a high level on an economical basis may not be possible.

The organic matter in the soil under cultivation is determined by the crop grown and the amount of cultivation. The data reported in Table 6 were obtained where the original soil had 3,250 pounds of

Table 6.—THE EFFECT OF CROPPING SYSTEMS ON SOIL NITROGEN.

Plot No.	Cropping system	Total nitrogen in surface 7 inches of soil			Percentage of total nitrogen depleted	
		Calculated for beginning of experiment[1]	After 25 years of cropping	After 50 years of cropping	1st 25 years	2nd 25 years
		Pounds per acre				
17	Corn, continuously.....	3,250[1]	1,575	1,420	52	5
9	Wheat, continuously....	3,250	2,040	1,750	37	9
23	Timothy, continuously..	3,250	2,485	2,363	24	4
39	Corn, oats, wheat, clover.	3,250	2,573	1,917	21	20
13	Corn, oats, wheat, clover timothy 2 years......	3,250	2,037	1,943	37	3

[1]Average nitrogen content for beginning of experiment was determined from average nitrogen analyses of samples taken from adjacent virgin areas.

nitrogen, and they show the effect of cropping system on the organic matter and nitrogen content of the soil (10). Corn, which requires cultivation, reduced the nitrogen from 3,250 pounds to 1,420 pounds per acre, while wheat, which requires no cultivation, reduced the nitrogen to 1,750 pounds per acre in the 50-year period. In the corn, oats, wheat, clover, and in the corn, oats, wheat, clover, and timothy rotation, the soil contained over 1,900 pounds of nitrogen per acre after fifty years. The soil on which timothy was grown continuously was plowed less frequently than that on which other crops were grown, and it had more nitrogen than any other soil. Even on this plot, more than one-third of the nitrogen was lost.

The failure of timothy to maintain the nitrogen (and organic matter) content of the soil is attributed to the fact that the timothy roots do not die each year, and that the crop was harvested. More nitrogen may have accumulated with an annual legume growing with

the timothy. The decomposition of soil organic matter which releases nitrogen is necessary for the production of crops like corn and wheat. The above data show that most of the decrease in soil nitrogen took place in the first 25 years. During the period when organic matter is decomposing rapidly, it is giving plant nutrients up rapidly also. During this period the supply of lime, phosphorus and other plant nutrients may be sufficient for normal crop production; the critical period for most plant nutrients begins when the decomposition of organic matter is decreased to a low level.

The application of 6 tons of manure per acre for 50 years in a rotation in Missouri increased the nitrogen content of the soil from 1,912 pounds to 2,698 pounds per acre (10) at the end of the period. The total increase in nitrogen was 786 pounds per acre, or 2.6 pounds per ton of manure applied. Data on the nitrogen content of the stable manure were not published.

The effects of 32 years of single crops and crop rotations on the soil organic matter and nitrogen in Ohio (1) are similar to those from Missouri (Table 7). Oats and wheat continuously maintained the organic matter and nitrogen contents of the soil at higher levels than did corn. The rotations including clovers maintained the organic

Table 7.—THE EFFECT OF CROPPING SYSTEMS ON SOIL ORGANIC MATTER.

Cropping system	Years	Organic matter	Nitrogen
		Pounds per acre in surface soil	
Corn, continuously...............	32	12,516	820
Oats, continuously................	32	21,722	1,300
Wheat, continuously..............	32	21,826	1,320
Corn, oats, wheat, clover, timothy...	32	26,515	1,540
Corn, wheat, clover...............	29	29,549	1,760
Original soil.....................	—	36,825	2,240

matter and nitrogen at higher levels than did non-legumes alone. The increase in organic matter where oats and wheat were grown, as compared to corn continuously, was probably due to less stirring of the soil where oats and wheat were grown. The still larger amounts of organic matter and nitrogen present where clover was grown was due to less cultivation, more nitrogen, and greater crop residues. Since organic matter is approximately 5% nitrogen, it is not possible to have organic matter without nitrogen.

The organic matter content of the soil was not increased signifi-

cantly by turning under 1.1 tons of cowpea hay each year for 20 years in Tennessee (15). Eighty tons of farmyard manure applied at the rate of 4 tons per acre annually for a 20-year period increased the organic matter only 2,200 pounds per acre. The 20-year average yield of wheat was:

Treatment	Yield—bus. wheat per acre
Cowpea green manure.................	25.5
Farmyard manure....................	25.5
After cowpea hay....................	15.8

Since the yield of wheat was increased by the manure and the cowpeas, the small increase in the organic matter may have been largely due to more crop residues where these treatments were used, rather than to direct increases from the manure and cowpeas.

Annual legumes for hay do not maintain the soil nitrogen and organic matter as well as legumes which live for two or more years, as is shown by data (12) in Table 8 from New York. The roots of annual

Table 8.—THE EFFECT OF DIFFERENT LEGUMES ON THE NITROGEN CONTENT OF THE SOIL.

Legume in rotation	Gain or loss of soil nitrogen, pounds per acre	Nitrogen in non-legume crop, pounds per acre per year
Red clover......................	532 gain	51
Alsike clover....................	595 gain	49
Alfalfa.........................	607 gain	66
Sweet clover....................	420 gain	51
Red clover and alsike clover........	577 gain	54
Sweet clover and vetch............	410 gain	51
Soybeans.......................	42 loss	29
Field beans.....................	100 loss	25

legumes die and decompose in the fall and winter in warm climates and give up much of their nitrogen to the leaching water before spring, whereas, legumes which live for two or more years, when plowed under in the spring, give up much of their nitrogen to the crops which follow.

In the South, crops produce unusually well after kudzu, as shown by data (20) from one test in Alabama:

Plot	2 crops of sorghum hay, pounds per acre	4 crops of corn, bushels per acre	7 crops of oats, bushels per acre
No kudzu....	3,264	15	17
Kudzu......	5,800	34	25

It takes three years to establish kudzu. Even though kudzu is a good crop to follow with other crops, it probably is too valuable to plow under for cultivated crops, and too expensive to grow for increasing nitrogen with the present low price of commercial nitrogen.

When young rye plants containing 1.86% nitrogen were turned into the soil (4), 73% of the material was decomposed in 30 days and 27% remained in organic matter; 69% of the nitrogen had been converted into a form available for plants, and 31% remained in the soil organic matter. Most young grasses and all legumes should have a nitrogen content of 1.8% or higher. Where materials containing over 1.8% nitrogen are turned into the soil, they decompose readily and give up their nitrogen.

When mature rye containing 0.24% nitrogen was turned into the soil (4), only 42% of the organic matter was decomposed in 60 days, and almost twice as much nitrogen as the rye contained was taken up from the soil and tied up in the bacteria and fungi which were decomposing it. The nitrogen which was taken up in the decomposition of the rye was available to plants before being used by the bacteria and fungi, and it was converted into the organic form which was temporarily unavailable to plants.

Nitrogen starvation in crops is often obtained with crops following oats in the summer or sorghum the following year. Nitrogen starvation has also been reported where residues from soybeans and lespedeza are turned under in the spring. These materials are low in nitrogen. Nitrogen starvation of crops is due to the soil microorganisms using up available soil nitrogen in the decomposition of crop residues, which prevents crops from getting sufficient nitrogen. Under these conditions liberal amounts of nitrogenous fertilizers will overcome the unfavorable effect of the low-nitrogen organic matter.

The carbon to nitrogen ratio of soil organic matter is approximately 10 to 1, which means that soil organic matter contains 10 times as much carbon as nitrogen. Materials like corn stalks and grain straws are low in nitrogen; the carbon to nitrogen ratio of these materials is 50 to 1 or higher. When they are turned under, the available nitrogen in the soil is used by the soil microorganisms in decomposition of these

materials until the carbon to nitrogen ratio approaches 10 to 1, after which nitrogen and carbon are given off, and the carbon to nitrogen ratio is maintained at about 10 to 1. Young grass and legumes have a carbon to nitrogen ratio which approaches 10 to 1 soon after being turned into the soil.

Either legumes or fallow restored the nitrogen balance after wheat in California (6):

Treatment	Yield-bu. of wheat per acre
Wheat, alternate fallow	40.0
Wheat, alternate vetch	38.7
Wheat, continuously	22.6

The roots and stubble of wheat (and other grain crops) are low in nitrogen, and during their decomposition nitrogen which would be available for other crops is tied up in the bodies of soil microorganisms which makes it unavailable for the crop during the next year. Fallowing the land or growing a legume crop on alternate years gave time for the grain crop residues to partially decompose and restore a favorable nitrogen balance in the soil. A favorable nitrogen balance might have also been restored by the application of nitrogenous fertilizers.

In dry climates good yields of wheat are dependent upon the amounts of available nitrogen (18) in the soil:

Treatment	Profit per acre
Continuous wheat	$5.41
Wheat and fallow	4.80
Wheat and field peas	13.71

One of the beneficial effects of fallow is to give the wheat stubble time to decompose, during which available soil nitrogen is first used in the decomposition of the stubble and later made available to crops through further decomposition of the organic matter. The yields of wheat are considerably higher after summer fallow than after wheat. The use of a legume, in the rotation, which consumed soil water overcame the unfavorable nitrogen balance produced by wheat stubble, and the combined profit on the wheat and peas was greater than the profit on continuous wheat or wheat and fallow.

The effect of straw on the yield of winter wheat and on the response of wheat to nitrate of soda is shown by the following data (19) from Washington:

Treatment	Yield wheat bushels per acre
Stubble only..	20
Stubble and straw...................................	18
Stubble and 150 pounds of nitrate of soda............	40
Stubble and straw and 150 pounds of nitrate soda.....	28

The straw reduced the yield 2 bushels without fertilizer and 12 bushels per acre with 150 pounds of nitrate of soda. Nitrate of soda raised the wheat yield to that of a normal crop in a wheat-fallow rotation.

Burning small grain crop residues and weeds and grass reduces the amount of material available for decomposition, and as a result less nitrogen is made unavailable to plants by soil microorganisms. Corn stalks would have about the same effect on soil nitrogen as small grain residues if they were chopped up and mixed with the soil as thoroughly. Due to the large size of corn stalks, their effect on nitrogen tie-up by soil microorganisms is of much less importance.

The following yields of wheat were obtained at the Ohio Agricultural Experiment Station (2) in 1938 after soybeans harvested by different means:

Disposition of soybeans	Bushels of wheat per acre
After combined soybeans...............	28
After binder harvested soybeans........	34
After soybeans for hay................	37

The appearance of the wheat after combined soybeans suggested a nitrogen deficiency. Since soybean straw is low in nitrogen, the available nitrogen in the soil may have been used up by the microorganisms in the decomposition of the straw, and the effect of the soybean straw was similar to that of grain straw, which is well known.

The sources of organic matter found in the soil are crop residues including the leaves, stems, and roots of plants, green manures, and stable manures. These plant materials vary considerably in their rate of decomposition. Some are succulent and tender and decompose readily, leaving little organic matter in the soil; others are tough and woody and decompose slowly, leaving organic matter in the soil for a long period of time. The sources of organic matter and their rapidity of decomposition as given by Blair and Waksman (4) are as follows:

1. **Green manures** decompose rapidly and liberate their nitrogen and phosphorus for plant growth, and leave little organic matter in the soil.

2. **Animal residues, such as dried blood, fish, and tankage,** also decompose rapidly; the nitrogen in these materials is made available rapidly, and little organic matter is left in the soil.

3. **Stable manures are ideal sources of organic matter.** Part of their minerals and nitrogen are rapidly liberated, and some organic matter is left in the soil; however the increase in soil organic matter from economical applications of stable manure is small (the author).

4. **Composts of plant residues are excellent sources of organic matter** if they have sufficient nitrogen to bring about active decomposition. Composts are too expensive for field crops (the author).

5. **Plant stubble, mature plant materials, such as straw, corn stalks, and pine needles,** decompose slowly in the soil. They are low in nitrogen and should be incorporated some time before a crop is planted, and under many circumstances it is desirable to fertilize the crops with nitrogen when these materials are turned under.

6. **Peat and forest litter** must be considered only as sources of organic matter, for they contain very little phosphorus and potash, and their nitrogen becomes available very slowly. They are too expensive for field crops (the author).

During decomposition organic matter gives up its nutrients slowly, and it contains rare elements as well as those commonly used in fertilizers. Also there is little danger in applying large quantities of well-rotted organic matter. For these reasons organic matter is an excellent source of nutrients in flower and greenhouse growing. Where sufficient stable manure is not available for greenhouse crops, an excellent artificial manure may be produced by applying a nitrogenous fertilizer to leaves, weeds, grain straw, waste hay, or other similar waste material. Mixing 75 to 100 pounds of nitrate of soda, sulphate of ammonia, cyanamid, or the equal in other sources of nitrogen per ton of dry material and building into a flat pile 4 to 6 feet high will bring about rapid decomposition, and a good source of organic matter is produced in a short time. The pile should be flat so that rain runs in rather than off.

The use of superphosphate, lime, and muriate of potash in making artificial manure has been recommended, but it is doubtful if these fertilizers will increase the rapidity of decomposition sufficiently to justify the added expense.

Plowing under crop residues and green manure crops produced higher yields of corn than subsurface tillage, which left the plant materials on the surface (5) in Iowa (Table 9). Plowing under the crop residues made an average of 17 bushels per acre more corn than subsurface tillage which left the crop residues on the surface. The stand of corn was better where the crop residues were plowed under than where they were left on the surface by subsurface tillage. The yield per stalk of corn was less in some comparisons with subsurface tillage, even though fewer stalks were present.

Table 9.—THE EFFECT OF PLOWING AND SUBSURFACE TILLAGE ON THE YIELD OF CORN.

Year	Soils	Plant material	Yield—bushels per acre	
			Plowed and surface planted	*Subsurface tillage, residues on surfaces*
1942	Clarion	Corn stalks	50	51
1942	Webster	Corn stalks	56	35
1942	Marshall	Red clover	88	68
1942	Marshall	Sweet clover	84	72
1942	Marshall	Alfalfa	106	65
1943	Clarion	Corn stalks	31	32
1943	Webster	Corn stalks	42	32
1943	Clarion	Oats, sweet clover	60	51
1943	Webster	Oats, sweet clover	54	52
1943	Marshall	Corn stalks	71	49
1943	Marshall	Red clover	91	41
1943	Marshall	Sweet clover	74	50
		Average	67	50

Plowing under crop residues was more effective than subsurface tillage for corn production (Ohio) in a three-year rotation of corn, wheat, alfalfa-clover-timothy mixed hay (16), as shown by data in Table 10. Plowing produced 8 bushels more corn than subsurface tillage. There was no improvement for subsurface tillage over the 8-year period.

Severe potash deficiency symptoms were evident in 1944 and 1945 with treatment number 5, where the crop residues were covered lightly.

Erosion was not a factor in this experiment. Where erosion is a factor, subsurface plowing which leaves crop residues on the surface would reduce erosion; however, the increase would have to be equal to the reduction in yield of 8 bushels of corn, due to leaving the residues on the surface, for the two practices to have equal value.

Mulching with a heavy layer of straw increased the yield only two bushels of corn.

Table 10.—THE EFFECT OF METHOD OF LAND PREPARATION ON THE YIELD OF CORN

Treatment	Yield per acre									Ferti-lized
	Unfertilized									4 yrs. Av.
	1938	1939	1940	1941	1942	1943	1944	1945	Av.	
	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.	Bus.
1. Plow+disc......	50	59	17	48	47	58	41	55	47	54
2. Sod plow only...	47	63	15	42	44	67	46	56	47	57
3. Rototiller.......	43	55	24	37	36	57	41	43	42	51
4. Subsurface......	36	49	15	36	29	57	41	50	39	49
5. Disc only[1]......	26	50	11	37	27	50	35	41	35	48
6. Plow+disc+ mulch........	50	59	15	51	51	71	57	51	51	61

[1] Disc only in 1944-1945, and rototilled or plowed shallow with sweeps to kill weeds, previously.

Both the Ohio and the Iowa data suggest that crop residues should be plowed under, rather than left on the soil.

Mulching corn with three tons of wheat straw increased the yield 28 bushels per acre on one year in North Carolina with high fertilization (11), as shown in Figure 5. The moisture content of the surface two inches of soil was considerably higher under the mulch than where no mulch was applied. It appears that mulching might not be an economical practice with corn; however, it may be profitable to mulch crops of high acre value.

The application of nitrogenous fertilizers to non-legume green manure crops has been less profitable than applying the nitrogen directly to the following crop. In Alabama (9) the yield of corn following oats for green manure, to which 40 pounds of nitrogen had been applied in the fall, was 17 bushels per acre; the yield was 35 bushels per acre where the nitrogen was applied directly to the corn without going through a green manure crop.

The application of all of the nitrogen directly to corn produced larger yields than did the application of two-thirds to corn and one-third to a rye cover crop in two tests in North Carolina (11). The yields of corn were 74 and 51 bushels where the nitrogen was applied directly to the corn, and 53 and 46 bushels per acre when one-third of the nitrogen was applied to rye green manure and two-thirds was applied directly to the corn in the two tests, respectively.

Where nitrogen is applied to grow a non-legume green manure crop, or on non-legume green manure crops and crop residues, like grain straw and crop residues, it is tied up in organic matter where its availability to plants is markedly reduced.
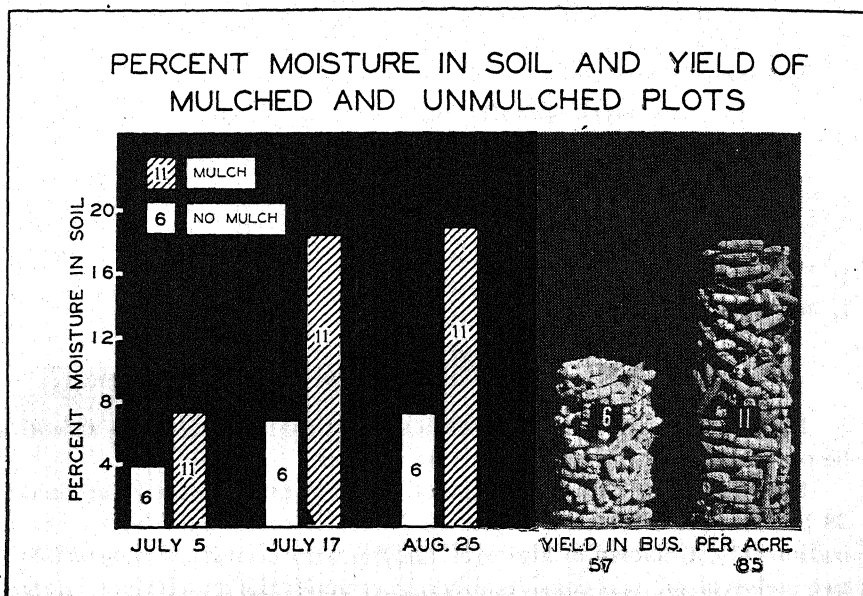
FIG. 5.—Corn yields and soil moisture (0-2 inch layer) were increased by mulching with 3 tons of wheat straw at lay-by time (11). (Courtesy North Carolina Agricultural Experiment Station.)

Since the primary value of soil organic matter is due to the nutrients which it supplies to plants on decomposition, it appears that nitrogenous fertilizers should be applied directly to the crop which is to be harvested, and in such manner that this crop will receive maximum benefit from it, rather than in conjunction with some material which will cause it to be tied up in an organic form. Non-legume green manure crops and crop residues are poor sources of nitrogen, and they have little place for field crops where commercial nitrogen is required for their decomposition.

SUMMARY AND CONCLUSIONS

Soil organic matter releases plant nutrients to crops when it is decomposed. Organic matter is decomposed by bacteria and fungi in the soil. These microorganisms are small plants, and they require nutrients just as crop plants require them.

The data reviewed on soil organic matter show that:

1. Economical crop production is dependent upon regular addition of nitrogen in the form of green manure, crop residues, stable manure, and commercial fertilizers from crop to crop or rotation to rotation.
2. A high organic matter content in soils is valuable, but it is too expensive to obtain on soils which are low in organic matter.
3. Most organic matter turned into cultivated soils is soon decomposed.
4. Annual legumes have little influence upon the organic matter and nitrogen content of cultivated soils.
5. Legumes which live for two or more years supply much more nitrogen to the following crop than do annual summer legumes.
6. Soil nitrogen (and organic) matter can be increased under sods, but it is soon lost when the sods are broken.
7. Soil microorganisms use up available nitrogen when they decompose plant materials which are low in nitrogen.
8. Nitrogen is more efficient for crop production when used directly for cultivated crops than when applied to aid in the decomposition of plant materials low in nitrogen.
9. Grain stubble and straw should be burned rather than plowed under where a crop is to follow.
10. Subsurface tillage, which leaves crop residues on the surface of the land, has been found to be less desirable than plowing residues under.

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The Agricultural Importance of Lime

Soils which contain too little lime are unproductive.

It has been estimated that from 100 to 500 pounds per acre of lime is leached out of the soils of the North Central States each year (37)[1]. The Tennessee River carries calcium and magnesium in solution equal to 348 pounds of lime per acre of water shed annually (34). Soils are acid because lime has been leached out; acid soils occur only in humid climates. When lime and other bases are leached out of the soil, their place on the clay is taken by hydrogen. The acid in soils is primarily clay acid. It is not soluble in water. The primary difference between clay acid and other common acids is that clay acid is very much weaker, and acid clay particles are much larger and can not be leached out of the soil. Clay acid combines with lime to form lime clay just as other acids combine with lime to form lime salts. Clay combines with potash, magnesium, sodium, and ammonia, as well as with calcium and hydrogen.

Calcium and magnesium are the elements for which lime is used. In the eastern and southeastern sections of the country where large quantities of fertilizer containing high amounts of sulphur are used, the acid sandy soils are often more deficient in magnesium than calcium. The use of dolomite in acid-forming fertilizers increases the yield of cotton more than does high-calcium lime.

The cell walls of plants contain calcium, and it combines with certain acids, like oxalic acid, formed inside of the plant. Magnesium is used in the manufacture of the (green) chlorophyll in the leaves of plants. The chlorophyll uses sunlight for energy and manufactures plant foods from carbon dioxide and water.

The growth of cultivated plants depends to a large extent upon the work of bacteria and fungi in the soil. The growth of crops without the application of nitrogenous fertilizers is made possible by the nitrogen which comes down in the rain and by that which bacteria living

[1]Numbers in parenthesis refer to the source of information, page 251.

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on crop residues in the soil and in the nodules of legumes take out of the air. In soils low in lime these bacteria take little nitrogen out of the air. That lime affects nitrogen fixation by bacteria living in the soil is illustrated by high lime soils which have grown good corn or cotton for as much as 100 years without the use of fertilizer. There are no low lime soils which have produced good crops for long without the use of nitrogen or legumes in rotation. The plant nutrients in soil organic matter are made available to plants when the organic matter is decomposed by bacteria and fungi.

Leguminous green manure crops grow slowly on strongly acid soils. Where fair yields of these crops are obtained in a long growing period,
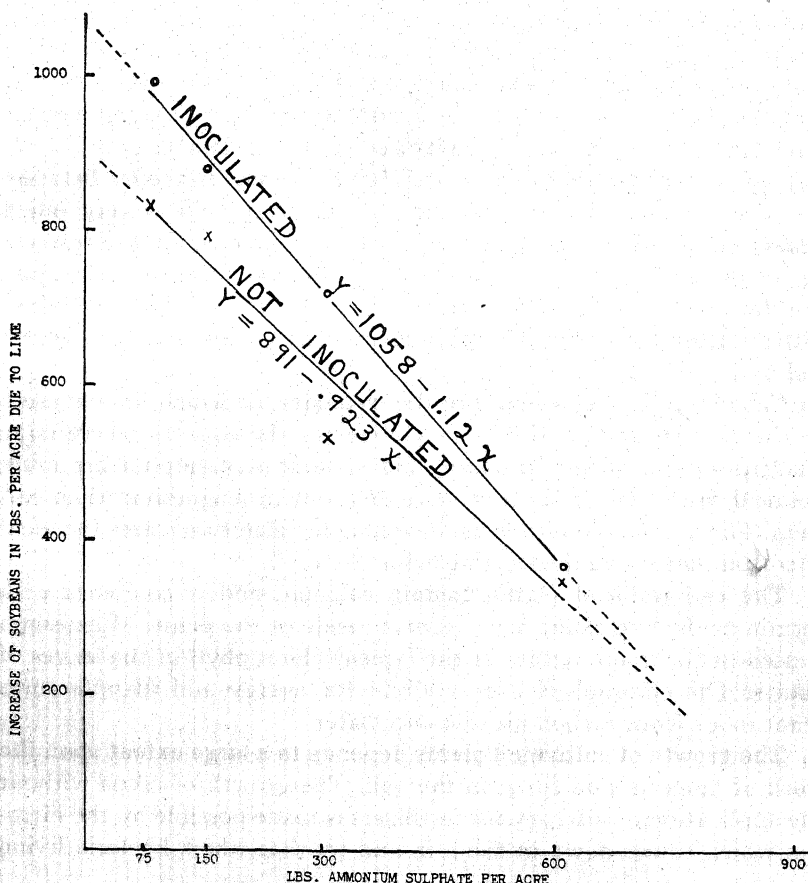
FIG. 1.—The response of soybeans to lime is low where the soil contains sufficient nitrogen (4). (Cut courtesy American Society of Agronomy.)

their decomposition after being turned into the soil may be too slow to supply crops which follow with nitrogen. Green manure crops grow more rapidly, and they decompose more quickly on soils high in lime than on soils low in lime. For these reasons green manure crops are generally more satisfactory on soils high in lime.

Legumes grown on soils low in nitrogen give much better response to lime (4) than those grown on soils which are high in nitrogen. The data illustrated in Figure 1 show that soybeans give a greater response to lime when the amount of nitrogen supplied by sulphate of ammonia is low. The data suggest that soybean root nodule bacteria are much more sensitive to a shortage of lime than are soybean plants. The adage that "manure is lime" is evidence of the fact that the nitrogen in manure partially overcomes the deficiency of lime in the soil by supplying nitrogen which enables crops like alfalfa to grow normally. The application of manure enables clovers and other legumes to be grown on soils which are too low in lime for normal growth. When the nitrogen needs of legumes are satisfied, plants do not require as much lime in the soil as when they depend upon nodule bacteria for nitrogen.

The early fertilizers were not acid forming and they usually maintained the fertility of the soil. At the present time, acid-forming fertilizer materials are being used which necessitate the use of lime, either in the fertilizer or applied separately. With the introduction of commercial fertilizers, the Southeast was able to devote land to cotton and other crops continuously, and successful crops have been produced without the use of leguminous green manure crops, which are dependent upon the use of lime.

The effect of lime, manure, and superphosphate on the yield of corn, wheat, and hay in Kentucky (29) is shown by data in Table 1. The use of lime and superphosphate in addition to manure increased the yield of first-year hay from 2,870 to 5,240 pounds per acre on the different experimental fields. The response of second-year hay to treatment was less marked, but good increases were obtained. The higher yields of leguminous hay crops resulted in a greater production of crop residues containing nitrogen which were plowed under for wheat and corn. The combination of the larger crop residues containing nitrogen with lime and superphosphate more than doubled the yield of wheat and increased the yield of corn from 7 to 25 bushels per acre.

The Middle Western and Northeastern states and other humid areas which have grown large acreages of legumes for hay or soil-building purposes have constantly used more lime than the Southern states.

Chemists were the first to investigate soil acidity. They were acquainted with acids and bases, the presence of either of which they determined by the use of litmus paper. The dye in litmus paper turns red when it comes in contact with acids and blue when it comes in contact with lime and other bases. Soils having an abundance of lime turn red litmus paper blue, and acid soils turn blue litmus paper red. The litmus paper test for lime in the soil is not used at the present time.

Table 1.—THE RESPONSE OF CROPS TO LIME AND PHOSPHATE (KENTUCKY).

Treatment	Experimental field				
	Berea	Fairston	Camp-bellsville	Green-ville	May-field
	Corn—bushels per acre				
No treatment...................	20.3	7.9	22.3	14.9	31.7
Manure........................	32.3	10.8	42.3	43.9	46.0
Manure, lime, superphosphate.....	57.5	35.9	64.1	50.6	71.1
	Wheat—bushels per acre				
No treatment...................	[1]	5.0	0.8	6.6	4.8
Manure........................	....	6.6	6.8	10.2	10.5
Manure, lime, superphosphate.....	....	18.0	20.3	23.0	26.3
	Hay, 1st year—pounds per acre				
No treatment...................	0	0	910	1,920	910
Manure........................	0	390	2,895	4,830	1,070
Manure, lime, superphosphate.....	5,240	5,400	5,970	7,700	4,840
	Hay, 2nd year—pounds per acre				
No treatment...................	1,110	0	[2]	1,680	520
Manure........................	1,145	550	....	3,590	600
Manure, lime, superphosphate.....	2,680	2,000	....	6,560	2,060

[1]Wheat was not grown at Berea.
[2]Stands were obtained on only one year.

Dyes are used which are sensitive over wider ranges in the lime content of soils.

The use of lime on acid soils stimulates plant growth, and as a result larger crop residues are returned to the soil, which, upon decomposition, leave a little humus which tends to increase granulation of the soil particles. Due to larger crop residues the organic matter should be maintained at a slightly higher level in limed than in strongly acid soils.

The lime problem is most important from the standpoint of keeping phosphorus available and potash from leaching. Even though crops

require calcium and magnesium for plant growth, their addition to the soil for keeping phosphorus available and potash from leaching out may be of more importance than their direct effect on plant growth.

Where crops are well supplied with commercial fertilizer containing large amounts of calcium and magnesium salts, they may thrive almost as well on strongly acid soils as on soils well supplied with lime. However, it should be borne in mind that on strongly acid soils crops generally require the application of more phosphate and potash than they do when grown on soils well supplied with lime. More nitrogenous fertilizer may also be required, due to smaller quantities being fixed by nitrogen fixing bacteria.

Both superphosphate and lime supply calcium to plants. Almost all of the calcium used in the cotton belt in the past has been in super-

Table 2.—THE RESPONSE OF SOYBEANS TO LIME AND SUPERPHOSPHATE.

Treatment	Yield of soybean hay, lbs. per acre
No treatment..	1,370
200 pounds of lime.................................	2,347
200 pounds of superphosphate......................	2,039
200 pounds of superphosphate, and 200 pounds of lime.	2,118

phosphate and in mixed fertilizers; superphosphate contains calcium equal to approximately 50% lime. The lime in superphosphate is combined with phosphorus and sulphur, which prevent it from reducing soil acidity. Except for the calcium supplied in fertilizers, most of the southern soils have received no lime. The unpublished data in Table 2 (Mississippi) indicate that soybeans respond to the lime in superphosphate. On this soil either superphosphate or lime served as a source of calcium for soybeans, and either served equally well. These data suggest that there may be many soils on which lime may increase the yield as much as superphosphate. Lime is much cheaper.

The effect of lime on the response of crops to phosphate (31) is shown by data in Table 3 from Ohio. Even though lime increased the yield of all crops markedly, its most outstanding effect was to reduce the need of grain crops for phosphate, which suggests that less phosphate-containing fertilizer is needed for these crops where the soil is limed. With hay crops about the same response to phosphorus was obtained on both limed and unlimed soil.

The amount of superphosphate recommended for crops by agricultural experiment stations is related to the lime recommendations. In the Southeast 48 pounds of phosphate or 267 pounds of 18% superphosphate is quite generally recommended each year for continuous cotton production. The cotton crop removes a total of approximately 12 pounds of phosphate per acre with the fertilizer recommended. The soil should have 36 pounds of phosphate annually more than that which becomes available from the soil particles to accumulate in the soil. In a livestock system of farming in Kentucky where manure is returned to the soil 300 to 400 pounds of superphosphate is recommended per rotation. The corn and wheat remove approximately 30 pounds of phosphate, which probably is not returned; the hay crops remove approximately 70 pounds of phosphate per rotation, not more than

Table 3.—THE EFFECT OF LIME ON THE RESPONSE OF CROPS TO SUPERPHOSPHATE.

Crop	Yield per acre				Increase for phosphate	
	Unlimed		Limed			
	No phosphate	Phosphate	No phosphate	Phosphate	Unlimed	Limed
Corn—bus........	28	42	45	55	14	10
Oats—bus........	32	50	43	52	18	9
Wheat—bus......	13	29	19	33	16	14
Clover—lbs.......	1,203	2,221	2,393	3,443	1,018	1,050
Timothy—lbs.....	1,702	2,346	2,795	3,349	644	554

one-half of which probably gets back on the fields from which it is harvested. The phosphate recommended for cotton production where little lime is used is about 4 times as much as that harvested; the phosphate recommendation in Kentucky where lime is used is about equal to the phosphate removed and not returned to the soil. The use of lime on cotton soils may over a long period of time reduce the phosphate requirement to the amount removed in the harvested crop or to one-fourth of that recommended at present.

The ratio of nitrogen, phosphorus, and potash in fertilizers for crops like cotton depends to a large extent upon the lime content of the soil. Data obtained from fertilizer analysis tests conducted in Mississippi on strongly acid soils show that a 4-8-4 fertilizer is more profitable than fertilizers containing more nitrogen. On soils containing more lime, an 8-4-6 fertilizer has been recommended where phosphorus and potash are deficient. On certain alkaline soils in Mississippi where

phosphorus is definitely much more limiting, the 8-4 nitrogen to phosphorus ratio is practically equal to an 8-8 ratio, and potash is not needed. The data suggest that the 1-2-1 and 1-3-1 ratios of nitrogen, phosphate, and potash so commonly used for cotton and truck crops could be reduced at least to a 1-1-1 ratio if sufficient lime were used to help to keep the applied phosphorus available.

The requirement of crops for phosphorus is reduced over a period of years where sources of nitrogen are used which conserve the lime in the soil, and increased where sulphate of ammonia, which depletes the lime supply of the soil, is used. The use of lime where sulphate of ammonia is used as the source of nitrogen should overcome the increased superphosphate requirement, and reduce the increased potash requirement, but the data available show that the increased leaching of potash where sulphate of ammonia is used can not be eliminated by using lime.

The chlorine, sulphur, and nitrogen which are not recovered in the harvested part of the crop are largely leached out of the soil. These elements carry calcium, magnesium, and potash out in the drainage water. If calcium and magnesium are present in large quantities, they will be leached out in the drainage water to a large extent instead of potash which costs about 20 times as much (per pound of nitrogen leached) as lime.

The effect of lime upon the amount of superphosphate required by crops is shown by data in Table 4 which were collected on Piedmont soils in North Carolina over a 16-year period (42). The rotation was corn, wheat, clover, and cotton. Without fertilizer, lime more than doubled the yield of all crops; with nitrogen and potash, the increase in the yield of most crops was more than trebled by lime. The profit per acre per rotation was $5.56 without lime and $28.31 with lime. The

Table 4.—EFFECTS OF VARYING AMOUNTS OF PHOSPHATE UPON INCREASED YIELDS AND NET PROFITS.

Pounds of 20% super-phosphate per acre[1]	Increased yield per acre								Net profit per acre per rotation over cost of fertilizers		
	No lime				Limed				No lime	Lime	In-crease
	Corn	Wheat	Red clover	Seed cotton	Corn	Wheat	Red clover	Seed cotton			
	Bus.	Bus.	Lbs.	Lbs.	Bus.	Bus.	Lbs.	Lbs.	Dol.	Dol.	Dol.
None......	4.7	0.5	29	221	17.2	5.2	802	505	5.56	28.31	22.75
81.........	19.6	10.2	192	793	36.0	17.4	2,353	1,220	47.28	91.59	44.31
162........	20.6	15.0	659	969	33.9	21.3	2,779	1,115	60.12	89.66	29.54
335........	29.0	19.8	1,365	1,158	36.2	23.8	3,348	1,065	77.58	89.65	12.07
670........	25.7	18.7	1,920	925	33.5	22.6	3,209	847	62.35	70.17	7.82
No fertilizer.	7.7	0.9	30	178	17.9	4.6	509	353	14.03	27.49	13.46

[1]All plots received 43 pounds of nitrogen and 43 pounds of potash per acre annually. The limed plots received 706 pounds of lime per acre per year.

equivalent of only 81 pounds of 20% superphosphate per acre was required with lime, while 335 pounds was required without lime for economical crop production. The profit for lime was $22.75, $44.31, $29.54, $12.07, and $7.82 per acre per rotation where none, 81, 162, 335, and 670 pounds of superphosphate was used per acre per year. The decreasing response to lime with increasing amounts of superphosphate indicates that superphosphate supplied lime to the crops.

The use of lime increased the efficiency of potash in a 4-year rotation in North Carolina as is shown by the data in Table 5 (42).

able 5.—Effects of Varying Amounts of Potash Upon Increased Yields and Net Profits

Pounds of 50% Muriate of potash per acre per year[1]	Increase in yield per acre								Net profits per acre per rotation over cost of fertilizer		
	No lime				Lime				No lime	Lime	In- crease
	Corn	Wheat	Red clover	Seed cotton	Corn	Wheat	Red clover	Seed cotton			
	Bus.	Bus.	Lbs.	Lbs.	Bus.	Bus.	Lbs.	Lbs.	Dol.	Dol.	Dol.
None......	16.9	12.6	363	435	22.7	17.4	2,214	284	33.74	42.26	8.52
43.........	19.9	12.7	504	679	29.1	21.7	2,716	592	45.72	66.25	20.53
86.........	20.6	15.0	659	969	33.9	21.3	2,779	1,115	60.12	89.66	29.54
172........	19.8	11.9	765	1,029	30.1	21.4	3,227	1,140	57.25	87.90	30.65
258........	19.0	15.3	1,074	1,016	29.1	22.5	3,088	1,171	59.48	87.33	27.85
No fertilizer.	7.7	0.9	30	178	17.9	4.6	509	353	14.03	27.49	13.46

[1]All plots received the equivalent of 650 pounds of 20% superphosphate and 43 pounds of nitrogen per acre per year. The limed plots received 706 pounds of lime per acre per year.

The use of the equivalent of 43 pounds of 50% muriate of potash per acre increased the profit $11.98 without lime and $23.99 with lime; the profit for 86 pounds of muriate of potash was $26.38 on unlimed soil, and $47.40 on limed soil. Apparently the use of lime enabled the crops to utilize the applied potash much more efficiently, which is in harmony with data from leaching experiments which show that the use of lime reduces the loss of potash by leaching. The response to lime was somewhat low, due to the high amount of superphosphate used.

The effect of lime on the response of cotton to potash is shown by data (38) from South Carolina reported in Table 6. The increase in yield of seed cotton from 4, 8, and 12% potash was 224, 255, and 275 pounds per acre on unlimed soil, and 341, 434, and 472 pounds per acre on limed soil, respectively. More seed cotton was produced with 4% potash on limed soil than with 12% potash on unlimed soil.

The above data indicate that dolomitic lime reduced the leaching of the potash and enabled higher amounts of potash to be used profitably by cotton. Dolomitic lime should conserve the potash supply to a greater extent than calcium lime where fertilizers contain high

Table 6.—THE EFFECT OF LIME ON THE RESPONSE OF COTTON TO POTASH.

Treatment	9-year average yield—pounds seed cotton per acre		Increase in yield for potash—pounds seed cotton per acre	
	Unlimed	Limed	Unlimed	Limed
6-8-0	411	426	...	...
6-8-4	635	767	224	341
6-8-8	666	860	255	434
6-8-12	686	908	275	472

amounts of sulphur, due to the high solubility of magnesium sulphate and the loss of sulphur as magnesium sulphate rather than as potassium sulphate.

A potash deficiency for cotton production rarely occurs in Mississippi on soils containing high amounts of lime. The strongly acid soils of the hill sections usually respond to potash; the high lime soils usually have sufficient potash.

Less potash was needed on limed than unlimed acid soil in experiments with peppers (35) in New Jersey (Table 7). The data show that greater yields were obtained on limed than on unlimed soil, and that crops on limed soil required less potash in the fertilizer. Increasing the potash on the unlimed soil caused the plants to have a pale green color, while the plants on the limed soil had a deep green color. Potash is usually applied as potassium chloride. Part of the chlorine which went into the soil tied up with potash may have leached magnesium out of the soil and produced a deficiency of magnesium which caused the plants to turn yellow. Similar results have been obtained in South Carolina on potatoes. Magnesium deficiency with high potash fertilization has also been reported from Indiana.

The application of lime to hay and other crops which contain large quantities of phosphorus and potash in the harvested part of the crop

Table 7.—THE EFFECT OF LIME ON RESPONSE OF PEPPERS TO POTASH.

Treatment	Unlimed soil	Limed soil
	Yield—bus. per acre	
5-10-0	268	297
5-10-5	268	324
5-10-10	329	406
5-10-15	356	405
5-10-20	345	359

reduces the available supply of these elements in the soil. Crops like cotton which remove only small amounts of phosphate from the soil give less response to phosphate where the soil is limed, and less phosphate is needed. The application of lime for crops like cotton and grain which remove little phosphate and potash from the soil where the stalks are left on the land should conserve more of the phosphorus and potash which become available over a period of years.

At the Sand Mountain Sub-Station in Alabama the use of lime (20) in a cotton, winter legume, corn rotation increased the yield during the first six years of the experiment; however, after 10 years it decreased the yield of cotton where 12 or 24 pounds of potash per acre was used annually. Lime was needed for the growth of the legume, and its use increased the yield of other crops. The reasons for lime reducing the yield are not known. However, Rogers (30) associated it with potash deficiency, and called attention to other cases of lime-induced potash deficiency. In the case referred to, one ton of lime was used every 10 years. If the potash deficiency was produced directly by lime, it appears that the results should have been produced in the early years of the test.

Any soil treatment which increases the yield of crops increases the needs for plant nutrients not supplied by the treatment because larger quantities of plant nutrients are harvested in the larger crop yields. The effect of one soil treatment on the removal of other nutrients is much more pronounced with hay crops and truck crops than with crops like corn and cotton.

Lime made the father rich and the son poor before commercial fertilizers were available. Lime made the father rich because it enabled him to produce larger crops; lime made the son poor because the larger yields produced by the father removed other plant nutrients from the soil, which resulted in lower crop yields being produced by the son. Commercial fertilizers are available at the present time to replace the plant nutrients removed in crops, which should prevent the use of lime by the father from making the son poor.

The lime content of the soil is expressed in a general way by pH, and different levels of lime are indicated as follows:

pH 7.0 to 8.0—too much lime but satisfactory for most crops unless produced by liming strongly acid soil.

pH 6.0 to 7.0—best lime content for most crops.

pH 5.5 to 6.0—lime satisfactory for most crops, but too low for sweet clover and alfalfa.

pH 5.0 to 5.5—lime too low for most crops.

pH below 5.0—lime extremely low for most field crops.

The above classification of the lime content of the soil as related to plant growth is general, and many variations may be found in the response of plants to lime on different soils of the same pH.

The total amount of hydrogen or lime and other bases in a soil depends upon its clay content. The pH of a soil is a relative figure, and it does not indicate the amount of hydrogen or lime (and other bases) present. The estimated amount of lime required to increase the pH of sandy loam, silt loam, and silty-clay loam soils from different pH levels to pH 6.0 and to pH 6.5 has been estimated (10) as shown in Table 8. At one pH the total amount of lime present is determined

Table 8.—THE APPROXIMATE AMOUNTS OF LIME NEEDED ON SOILS OF DIFFERENT TEXTURE AT DIFFERENT PH.

pH of unlimed soils	Tons of lime per acre to increase to pH 6.0 to 6.5					
	Sandy loam		Silt loam		Silty clay loam	
	pH 6.0	pH 6.5	pH 6.0	pH 6.5	pH 6.0	pH 6.5
6.0	...	0.5	...	0.9	...	1.25
5.5	0.5	1.0	0.9	1.8	1.2	2.50
5.0	1.0	1.5	1.8	2.7	2.5	3.75
4.8	1.2	1.7	2.1	3.0	3.0	4.25

by the amount of clay. The availability of the lime to plants is influenced to a considerable extent by the kind of clay in the soil.

Cowpeas and soybeans are usually listed as being tolerant to high and moderate soil acidity, respectively. The yield of soybeans at the Mississippi Agricultural Experiment Station (4) on a soil of pH 5.5 was increased from 1,056 to 2,013 pounds per acre by the use of lime (Figure 1). The yield of cowpeas was increased from 2,700 to 4,080 pounds of hay per acre, and from 20 to 26 bushels of peas per acre by the use of 500 pounds of ground lime per acre (3). Cotton has also been listed as tolerant to high acidity, but good increases in yield have been obtained from the use of lime on cotton.

The tolerance of field crops to a deficiency of lime as indicated by pH is illustrated by the data (36) from Alabama reported in Table 10. The yield of soybeans, cowpeas, sorghum, corn, and Sudan grass increased with each increase in pH from 4.55 to 5.85. The soil is sandy; heavier soils have more lime at the same pH.
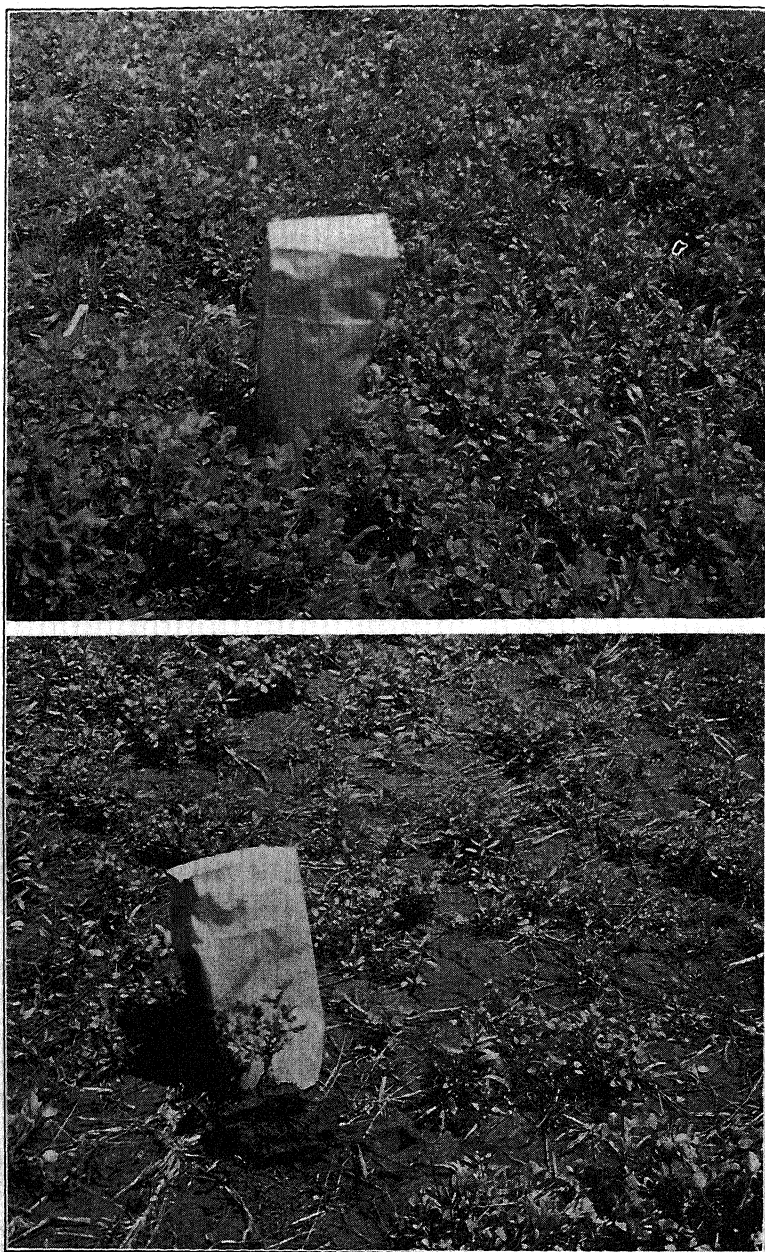
FIG. 2.—The difference in winter survival of sweet clover was due to the use of 600 pounds of lime in the drill with the seed (top) (2). (Cut courtesy Missouri Agricultural Experiment Station.)

Table 9.—A GROUPING OF PLANTS ACCORDING TO RESPONSE TO SOIL ACIDITY (10).

Plants tolerant of high acidity	Plants tolerant of moderate acidity	Plants tolerant of slight acidity	Plants very sensitive to acidity
Blueberries	Alsike clover	Asparagus	Alfalfa
Carpet grass	Austrian winter peas	Barley	Beets
Cotton	Bermuda grass	Brussel sprouts	Sweet clover
Cowpeas	Carrot	Cabbage	
Crotalaria	Corn	Cantaloupe	Abelia
Potatoes	Dallis grass	Cauliflower	Alyssum
Red Top	Eggplant	Celery	Anemone
Rye	Garden peas	Crimson clover	Aster
Snap beans	Kale	Cucumber	Begonia
Soybeans	Kudzu	Hop clover	Bell Flower
Tobacco	Lespedeza	Lettuce	Box wood
Watermelons	Lima beans	Okra	Bittersweet
	Mustard	Onions	Calendula
Galax	Oats	Parsnip	Carnation
Hydrangea	Strawberries	Peppers	Chrysanthemum
Magnolia	Sweet potato	Pumpkin	Clematis
Mountain Laurel	Tomatoes	Radish	Cornflower
Rhododendron	Turnip	Spinach	Dahlia
	Velvet beans	Squash	Forsythia
	Vetch	White clover	Gaillardia
	Wheat		Geranium
		Ageratum	Gerbera
	Azalea	Castor bean	Gladiolus
	Ferns	Cosmos	Honeysuckle
	Ladyslipper	Gardenia	Hydrangea
	Pitcherplant	Heathers	Larkspur
	Sand Myrtle	Holly	Lilac
	Trailing Arbutus	Iris	Marigold
	Trillium	Juniper	Narcissus
	Venus fly trap	Lily	Nasturtium
		Lupines	Pansy
		Petunia	Peony
		Phlox	Poppy
		Poinsettia	Primrose
		Portulaca	Privet
		Scabiosa	Rose
		Scarlet sage	Snapdragon
			Sweet pea
			Zinnia

Table 10.—THE RESPONSE OF DIFFERENT CROPS TO LIME.

Nitrogen source	pH 1927	Average yield (1926-1928)—pounds of hay per acre				
		Soybean	Cowpeas	Sorghum	Entire corn plant	Sudan grass
Cyanamid	5.85	1,832	1,097	5,389	3,032	2,640
Nitrate of soda	5.50	1,402	1,163	3,693	1,894	1,608
None	5.45	959	783	2,259	1,437	879
Sulphate of ammonia	4.55	556	988	838	1,015	200

Both lime and superphosphate increased the yield of crops in
Kentucky (29). In the case of corn and wheat (Table 11) the increase

Table 11.—The Effect of Lime and Superphosphate on the Yield of Crops
in Kentucky.

Crops	Yield without limestone or phosphate	Crop yield increases		
		For limestone	For super-phosphate	For lime-stone and super-phosphate
Berea Field. Started 1913. Similar to Colyer silt loam				
Corn—bus...................	26.0	11.1	13.2	19.0
Soybean hay—lbs..........	2,920	695	907	1,271
Mixt. clover hay—lbs........	661	473	796	2,215
Fariston Field. Started 1916. Similar to Tilsit silt loam.				
Corn—bus...................	11.9	9.9	16.0	35.4
Soybean hay—lbs............	1,528	755	971	3,090
Wheat—bus.................	2.6	2.0	4.7	11.4
Mixt. clover hay—lbs.........	238	371	892	3,230
Campbellsville Field. Started 1919. Similar to Christian silt loam				
Corn—bus...................	28.6	4.0	23.0	25.3
Wheat—bus.................	4.3	1.5	7.0	9.2
Mixt. clover hay—lbs.........	1,373	260	1,588	2,119
Greenville Field. Started 1913. Tilsit silt loam				
Corn—bus...................	27.7	2.4	10.6	20.1
Soybean hay—lbs............	1,960	341	800	1,587
Wheat—bus.................	6.1	1.2	6.9	12.4
Mixt. clover hay—lbs........	1,283	176	1,484	2,448
Western Ky. Exp. Sub-station. Sandstone soil. Started 1928. Tilsit silt loam.				
Corn—bus...................	22.4	....	10.7	17.5
Wheat—bus.................	3.0	....	7.5	11.0
Mixt. clover hay—lbs........	1,076	....	1,248	2,741
Western Ky. Exp. Sub-station. Limestone soil. Started 1926. Similar to Decatur silt loam				
Corn—bus...................	43.2	5.3	7.1	11.8
Wheat—bus.................	10.8	1.0	3.7	6.3
Mixt. clover hay—lbs........	1,731	1,099	1,034	2,159
Russellville Field. Started 1913, discontinued 1924, similar to Decatur silt loam.				
Corn—bus...................	30.0	8.7	7.1	14.9
Soybean hay—lbs............	2,003	657	428	758
Wheat—bus.................	10.0	0.2	3.2	7.8
Mixt. clover hay—lbs........	1,626	1,190	755	2,026
Hopkinsville Field. Started 1922, discontinued 1929. Decatur silt loam.				
Corn—bus...................	33.0	5.9	3.7	11.7
Wheat—bus.................	6.0	1.0	5.7	7.3
Clover and Soybean hay—lbs..	1,826	847	1,774	2,542

Table 11.—Continued.

Crops	Yield without limestone or phosphate	Crop yield increases		
		For limestone	For super-phosphate	For limestone and super-phosphate
Mayfield Field. Started 1913. Grenada silt loam.				
Corn—bus....................	36.5	10.6	2.1	11.7
Soybean hay—lbs............	2,411	662	161	930
Wheat—bus.................	9.6	4.7	3.5	10.1
Mixt. clover hay—lbs........	1,627	1,637	733	2,743
Lone Oak Field. Started 1913, discontinued 1923. Grenada silt loam.				
Corn—bus....................	32.7	5.2	2.7	7.3
Soybean hay—lbs............	2,495	373	269	719
Wheat—bus.................	11.1	0.7	1.5	7.3
Mixt. clover hay—lbs........	1,573	884	356	1,974
Average of all fields.				
Corn—bus....................	29.2	7.0	9.6	17.5
Soybean hay—lbs............	2,218	580	599	1,393
Wheat—bus.................	7.3	1.5	4.9	9.2
Mixt. clover hay—lbs........	1,301	771	1,066	2,420

in yield from lime and superphosphate was approximately equal to the increase from lime plus the increase from superphosphate when used separately; in the case of hay crops the increase in yield from lime and superphosphate was usually considerably greater than the increase from lime plus the increase from superphosphate when used separately. The use of lime enabled the recovery of a much higher percentage of the applied phosphorus; phosphorus is much more expensive than lime.

The use of lime in addition to superphosphate increased the average yield of corn 7.9 bushels, soybean hay 794 pounds, wheat 4.3 bushels, and mixed clover hay 1,354 pounds per acre. Both lime and phosphate were profitable, but, due to lower cost, lime was more profitable than phosphate. The increase in yield of the corn and wheat no doubt was dependent to a large extent upon the nitrogen left in the soil from the legume crops. The soils used in these experiments were silt loams. The residual effect of the legumes would be expected to be less in lighter soils and in warmer climates.

Ground limestone requires some time in the soil to become available. The illustrations in Figure 3 show that lime applied for red clover
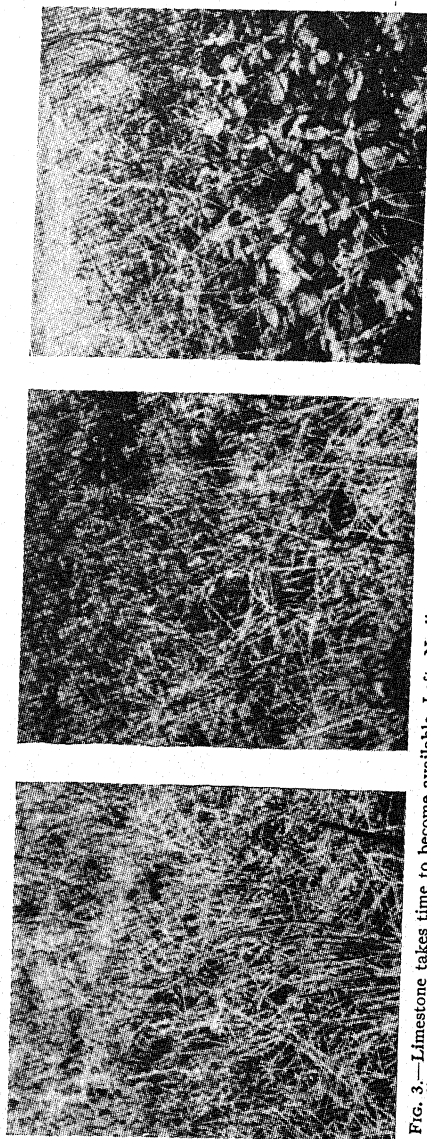
Fig. 3.—Limestone takes time to become available. Left: No lime, and no clover. Center: Little clover where planting followed immediately after application of lime. Right: Lime was applied a year before planting red clover which was good (9).

was much more effective when applied one year before planting than when applied immediately before planting (9). Ground limestone is relatively insoluble, and considerable working is necessary for it to become thoroughly mixed with the soil. If lime is applied to the land one year in advance of planting crops highly sensitive to lime, and the land is used for a cultivated crop, it should become thoroughly mixed with the soil. Where lime is applied in direct contact with the seed, it is immediately available to the plants.

Lime doubled the yield of red clover in rotation, and the yields of corn and wheat were increased considerably in tests in Virginia (24). The data (Table 12) show that less phosphate and potash were required

Table 12.—THE EFFECT OF NITROGEN, PHOSPHATE, AND POTASH WITH AND WITHOUT LIME ON THE YIELD OF CORN, WHEAT, AND RED CLOVER ON BERKS SILT LOAM. 1935-1940.

Fertilizer treatment[1]	Corn average yield bushels per acre		Wheat average yield bushels per acre		Clover average yield pounds per acre	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
0.............	12	21	6	13	604	1,379
P.............	21	27	14	22	1,050	2,279
P-K...........	26	41	14	24	1,187	2,569
N-P...........	24	29	15	22	1,210	2,408
N-P-K........	31	47	17	24	1,477	2,989
N-P-2K.......	36	49	19	26	1,822	3,263
N-P-3K.......	38	49	20	27	1,750	3,348
N-2P-K.......	36	46	20	28	1,777	3,218
N-2P-2K......	38	50	22	28	1,783	3,365
N-K..........	17	38	9	17	1,035	2,382
2N-2K........	21	43	9	21	1,198	2,702

[1] 0 = no treatment; N = 20 lbs. of nitrogen per acre annually; P = 32 lbs. phosphate per acre annually; K = 20 lbs. potash per acre annually.

on the limed soil. Lime was used at the rate of two tons every three years before the experiment was started, and at the rate of two tons every six years during the experiment.

The effect of lime and fertilizer on the yield of grain crops in rotations with legumes is determined to a large extent by their effect on the legume (11) (Ohio) (Table 13). The yield of timothy which was grown with clover was directly proportional to the yield of clover. The yield of corn following timothy and clover was closely related to the yield of the clover. The relation of the yield of the clover to the yield of oats and wheat was significant but less marked than that of corn. Apparently, lime increased the yield of clover which increased the supply of nitrogen available for the timothy and grain crops.

Table 13.—THE RESPONSE OF CROPS IN A ROTATION TO LIME.

Crop	No fertilizer	Lime[1]	Fertilizer	Lime and fertilizer
	Yield per acre			
Corn—bus.........	11	26	26	47
Oats—bus..........	25	39	42	45
Wheat—bus........	6	15	18	26
Clover—lbs........	594	1,906	1,269	2,881
Timothy—lbs......	887	2,961	1,316	3,754

[1]During the 5-year rotation two tons of limestone, 300 pounds each of superphosphate and nitrate of soda, and 200 pounds of muriate of potash were applied per acre.

In a 2-year rotation of corn and soybeans followed by vetch in the fall, which was plowed under in the spring for cotton, lime (20) increased the yield of green vetch 2,802 pounds, green soybeans 2,864, corn 6.4 bushels, and seed cotton 239 pounds per acre (Alabama).

Gypsum is calcium sulphate. It is used to top-dress peanuts. Gypsum applied to the foliage is more valuable for peanuts on soils low in lime than dolomitic limestone applied in the row (28). Neither gypsum nor dolomitic lime increased the yield of peanuts on soils high in lime.

Ground limestone and hydrated lime had equal value for crops in a four-year rotation in Pennsylvania (40). The rotation was corn, oats, wheat, and clover and timothy hay. The heavy application of lime lasted for 16 years. The intermediate rate of lime was applied preceding the clover and timothy, and was a little superior to the other two rates of lime (Figure 4).

The response of tomatoes to regular lime as compared to dolomite with different sources of nitrogen is shown by the data in Table 14 from New Jersey (35). Fifteen hundred pounds of 5-8-7 fertilizer was applied per acre. Dolomite was much more effective for increasing the yield of tomatoes with both sources of nitrogen than was calcium lime.

Table 14.—THE EFFECT OF SOURCE OF LIME ON THE YIELD OF TOMATOES.

Treatment	1935	1936	1937	1938	1939	Average
	Tons of tomatoes per acre					
Sulphate of ammonia—no lime..	13.3	8.5	5.6	6.7	7.0	8.2
Nitrate of soda—no lime.......	13.7	8.2	5.7	8.1	7.7	8.7
Sulphate of ammonia—lime....	16.4	9.6	7.9	7.9	8.2	10.0
Nitrate of soda—lime..........	14.6	10.3	8.5	8.0	8.2	9.9
Sulphate of ammonia—dolomite.	18.0	12.6	10.0	10.1	9.4	12.0
Nitrate of soda—dolomite......	17.7	12.1	8.8	10.6	9.5	11.7

On soils badly deficient in magnesium, dolomite is a better source of lime than high calcium lime. Dolomite should be given preference on extremely sandy soils where large amounts of sulphur have been used in the fertilizer.

At the New Jersey Agricultural Experiment Station (7) where 1,000 pounds of 5-8-10 fertilizer was used, and 1,000, 2,000, and 4,000 pounds
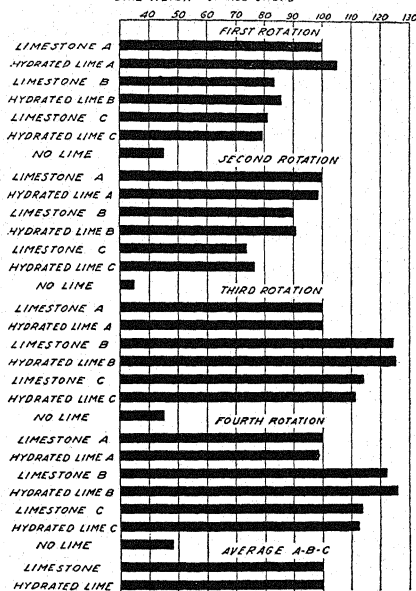
FIG. 4.—The relative value of limestone and hydrated lime for the production of corn, oats, wheat, and timothy and clover hay. A = 4,450 pounds equivalent of limestone for 16 years, B = 1,113 pounds every 4 years, and C = 556 pounds every 2 years (40).

of lime was applied, beets, carrots, sweet potatoes, cabbage, sweet corn, lima beans, peppers, string beans and eggplants produced considerably higher yields at a pH from 6.0 to 7.0 than below pH 6.0. Liming the soil to pH 5.2 to 5.6 reduced the need for higher amounts of phosphorus, eliminated the need for magnesium sulphate, and increased the yield of potatoes.

Potato scab is most prevalent on soils with a pH of 5.5 to 7.5 in the Northeast. There is some scab below pH 5.5, and more on soils above 7.5 (23). In North Carolina 10 to 20% of the surface of potatoes has been found to be scabby at a pH of 4.6.
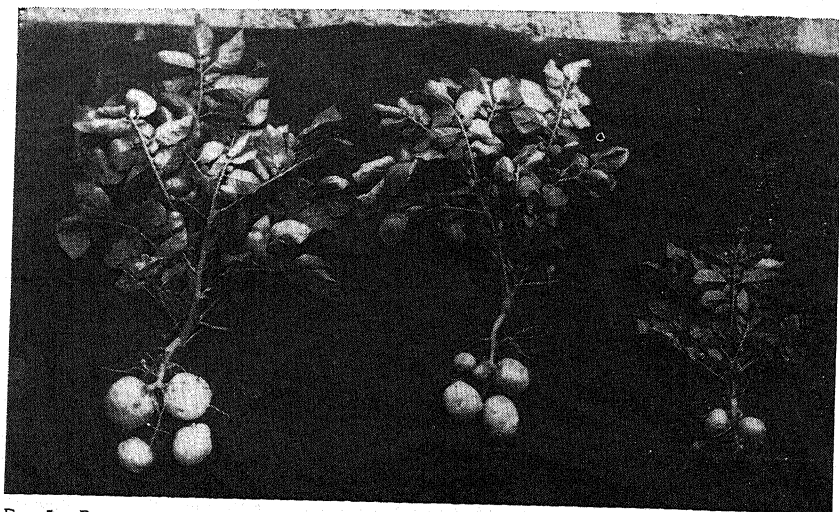
Fig. 5.—Potatoes on strongly acid soils respond to lime. Left, dolomite, pH 5.2; center, unlimed, pH 4.8; right, sulphur, pH 4.5 (6). (Courtesy South Carolina Agricultural Experiment Station.)

The use of dolomite to neutralize acid-forming fertilizers has increased the yield of potatoes on many soils; and in many cases scabbiness of potatoes has been increased.

Sulphur has been used to lower the lime content of the soil to reduce scabbiness of potatoes, which often lowers the yield. Obviously, potatoes should be planted on soil which is relatively free of scab where possible.

Higher yields of potatoes were produced where lime was placed 10 inches below the surface in pot tests (23) conducted in North Carolina than where the lime was mixed in the surface soil. Placing the lime 10 inches below the surface increased the yield over 100 bushels per acre more than mixing it with the top 10 inches of soil; a definite decrease in scabbiness was found with deep placement of lime (Table 15) as compared to mixing it with the top soil. No data are yet available on deep placement of lime under field conditions.

Table 15.—THE RESPONSE OF POTATOES TO LIME.

Treatment	Yield—bus. per acre		Percent of total surface scabby
	No. 1	No. 2	
No lime................................	20	119	0.3
Lime mixed in top 10 inches of soil........	43	136	7.2
Lime applied 10 inches below surface.....	183	101	0.1

On the basis of the data obtained in pots, the application of lime 10 inches below the surface supplied calcium to the potato plants, and at the same time the zone in which the potatoes were produced was favorable to the growth of scab free potatoes. The movement of lime in the soil is so slow that lime placed 10 inches below the surface should not move up enough to increase scabbiness in potatoes for several years.

Calcium silicate slag was superior to limestone in pot experiments in Tennessee (17). The superiority of the slag was attributed to its phosphorus content, which is equal to 125 to 160 pounds of 20% superphosphate per ton of slag. Calcium silicate slag contains about 85% lime, and one to two pounds of borax per ton. Overliming injury from the application of calcium silicate slag is rare; however, too much of this material produced overliming injury on two soils in Alabama (21).

Calcium silicate slag should not be mixed with superphosphate which is to be applied to row crops, and it should probably not be mixed with superphosphate for any purpose unless it is to be applied immediately. For neutralizing acid fertilizers calcium silicate slag was only about one half as good as dolomite which increased the yield 58 pounds of seed cotton per acre in Alabama (43). In Mississippi (5) the use of ground and granular calcium silicate slag to offset the acidity of cotton fertilizers made no increase in the yield on soils on which dolomite increased the yield 59 to 114 pounds of seed cotton per acre.

Sweet potatoes may have scurf or pox where large quantities of lime are used, but they are responsive to lime, and the pH probably should be above 5.5.

The amount of lime to use per acre depends to a certain extent upon the crop grown. Alfalfa requires a high lime soil, and usually no attempt to grow alfalfa without lime should be made unless the lime content of the soil is such that the pH is approximately 6.5. A test on the effect of rates of lime on the yield of crops was conducted by the Kentucky Agricultural Experiment Station (15,29), and the results are reported in Table 16. The rotation was corn, wheat, and mixed grasses and lespedeza for hay. The lime treatments were one-third of a ton every three years, one ton every 9 years, and two tons every 18 years. The test was started in 1927, and the data were reported through 1938. There was little difference in the increase in yield from the rates of lime used, except that alfalfa and clover failed on all plots which received less than 2 tons of lime per acre.

Where the legume in the rotation is lespedeza, cowpeas, or soy-

beans, it appears that one-third of a ton of lime every three years is equal to higher amounts at less frequent intervals. In fact the smaller applications were just as good as the two-ton application on the Kentucky soils which had run only 12 of the 18 years. Where larger quantities of lime are applied at less frequent intervals, the leaching of lime is greater than where the smaller quantities are applied more frequently.

The amount of lime necessary to use in a cotton-vetch, or corn-vetch system of farming, which has come into use in certain sections of the cotton belt, (for more details see Chapter 7), will probably have to be greater than one-third of a ton per acre every three years. It appears that 1,000 pounds per acre every three years might be

Table 16.—THE EFFECT OF AMOUNT AND FINENESS OF GRINDING LIME ON THE YIELD OF CROPS.

	Increase in yield		
Lime treatment	Corn, 11 crops	Wheat, 12 crops	Mixed hay, 11 crops
	Bushels	Bushels	Pounds
⅓ ton 10-20 mesh per inch.......	8.1	2.6	1,723
⅓ ton 40-50 mesh per inch.......	10.9	3.7	2,034
⅓ ton 70-80 mesh per inch.......	9.6	3.0	1,818
⅓ ton 100-mesh per inch.........	7.6	3.5	1,516
1 ton 10-mesh...................	10.6	4.8	1,288
2 tons 10-mesh..................	10.8	5.0	1,893
Av. of ⅓-ton applications........	9.0	3.2	1,773
None..........................	47.8	14.1	2,504

necessary to take care of the lime needs where a good leguminous green manure crop is turned under each year.

The fineness of grinding limestone as shown by the above data is relatively unimportant. The 100-mesh and finer limes were slightly inferior to the coarser material for crop production. The specifications for ground limestone in Kentucky, 90% through an 8-mesh sieve with none of the dust removed, appears satisfactory.

Lime may produce decreases in yield unless consideration is given to the soil and the quantity of lime used. The data reported in Table 17 were obtained on Norfolk sandy loam (41) in North Carolina. Four thousand pounds of lime was used in 1918 and 2,000 pounds in 1921, which is now regarded as entirely too much for a soil so low in clay. The three-year rotation was corn interplanted with cowpeas,

cotton followed by crimson clover in the fall and plowed under the following spring, and harvested peanuts followed by crimson clover plowed under for corn. The crimson clover and cowpeas did not make good growth. The tests were conducted in 3 different fields. The data as a whole show that lime had very little effect on the yield of crops with possibly significant decreases in yield of cotton. No increase in yield and often decreases in yield are obtained where high rates of lime are used on soils with a low clay content. Unless crops like alfalfa are grown which require large amounts of lime, equally good, if not more satisfactory, results are obtained with 750 to 1,000 pounds of lime per acre every 3 years, and at the same time over-liming injury is avoided.

Table 17.—THE APPLICATION OF TOO MUCH LIME MAY BE INJURIOUS.

Fertilizer treatment	Increase in yield per acre		
	Corn	Seed cotton	Peanuts
	Bushels	Pounds	Bushels
0........................	−2.2	−22	−4.6
½ (NPK)................	3.1	101	1.4
(NPK)...................	−1.0	−122	1.9
1½ (NPK)..............	3.2	23	−1.5
2 (NPK)................	0.3	−219	4.9
2½ (NPK)..............	1.6	−232	6.2

Overliming may result in boron becoming unavailable. The application of 10 to 20 pounds of borax per acre usually overcomes over-liming injury. The Alabama Experiment Station (21) found that "the use of five pounds of borax per ton of lime was sufficient to prevent boron deficiencies regardless of the amount of lime applied". The use of acid-forming sources of nitrogen tended to overcome lime-induced boron deficiency. Cottonseed meal overcame boron deficiency with cotton. Nitrate of soda tended to increase boron deficiency.

Boron deficiency developed on grapes in South Carolina (32) where 1,500 pounds of dolomite was applied in 1932, and 1,000 pounds per acre of basic slag was applied in 1938. Boron applied in 1940 and 1941 increased the average yield of 33 varieties of grapes from 3.2 to 7.6 pounds per vine. In another test boron increased the yield of grapes from less than one pound to as much as 14 pounds per vine. Boron was applied at the rate of 10 pounds of borax per acre.

"Alfalfa yellows" is a discoloration of the leaves produced by boron

deficiency. The application of 10 pounds of borax per acre increased the yield of alfalfa hay from 5,009 to 7,355 pounds per acre (14) in Virginia. The effect of boron on the yield of alfalfa in 43 demonstrations in Tennessee (13) is shown by the data in Table 18. Twenty pounds of

Table 18.—THE RESPONSE OF ALFALFA TO BORON, 43 DEMONSTRATIONS.

Treatment	1st cutting	2nd cutting	3rd cutting	4th cutting	Total
	Yield—pounds alfalfa hay per acre				
None*	838	1,368	1,035	1,019	4,260
Borax, 20 lbs	1,020	1,741	1,347	1,240	5,348
Borax, 20 lbs.; potash, 200 lbs.	1,160	1,986	1,489	1,413	6,048
Potash, 200 lbs............	1,043	1,687	1,306	1,290	5,326

*All plots received farmer's normal lime and fertilizer treatment. In all cases lime was used, and except in Central Basin, phosphate was used. In a few cases manure also was used.

borax increased the average yield of alfalfa 1,088 pounds per acre without potash and 712 pounds per acre with potash. In 1942 over 90% of the demonstrations on alfalfa in Tennessee gave significant response to boron. Borax may be necessary for alfalfa production on most soils which require lime.

The rate of application of borax recommended for crops which respond to borax (26) is shown in Table 19. The higher rates of application are recommended for soils high in organic matter, clay, and lime. The smaller rates are recommended when the crops are grown on sandy soils, on soils low in organic matter, and on soils low in lime. Since many crops are injured by the application of too much borax, it is suggested that broadcast applications are more desirable.
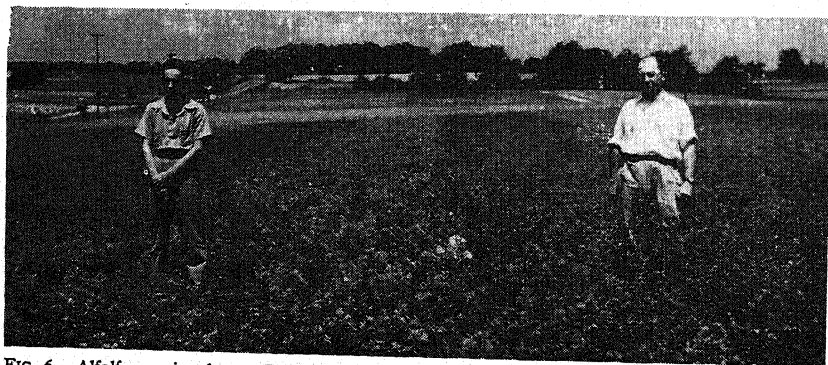
FIG. 6.—Alfalfa requires boron. The dark strips received 20 pounds of borax per acre 20 days before the picture was taken (14). (Courtesy Virginia Agricultural Experiment Station.)

Table 19.—PLANTS SHOWING BORON DEFICIENCY IN THE UNITED STATES AND RANGE OF FIELD RECOMMENDATIONS MADE IN VARIOUS STATES FOR DEFICIENT SOILS.

Plant	Recommendation lbs. borax per acre	Plant	Recommendation lbs. borax per acre
Apples[1]	5-30	Narcissus	None
Alfalfa	10-40	Pears[1]	½ lb. per tree
Beets	10-50	Prunes	None
Broccoli	10	Potatoes	25
Cabbage	10-12	Radishes	10-20
Carrots	10-20	Rutabagas	10-25
Cauliflower	10-25	Strawberries	10-12
Celery	10-100	Sugar beets	10-40
Corn	10	Tobacco	½-10
Cotton	½-10	Tomatoes	10-20
Eggplant	10-20	Tung trees	None
Lettuce	10	Turnips	10-30
Mangels	10		

[1]Boric acid used for apples and pears in Washington and for apples in Montana.
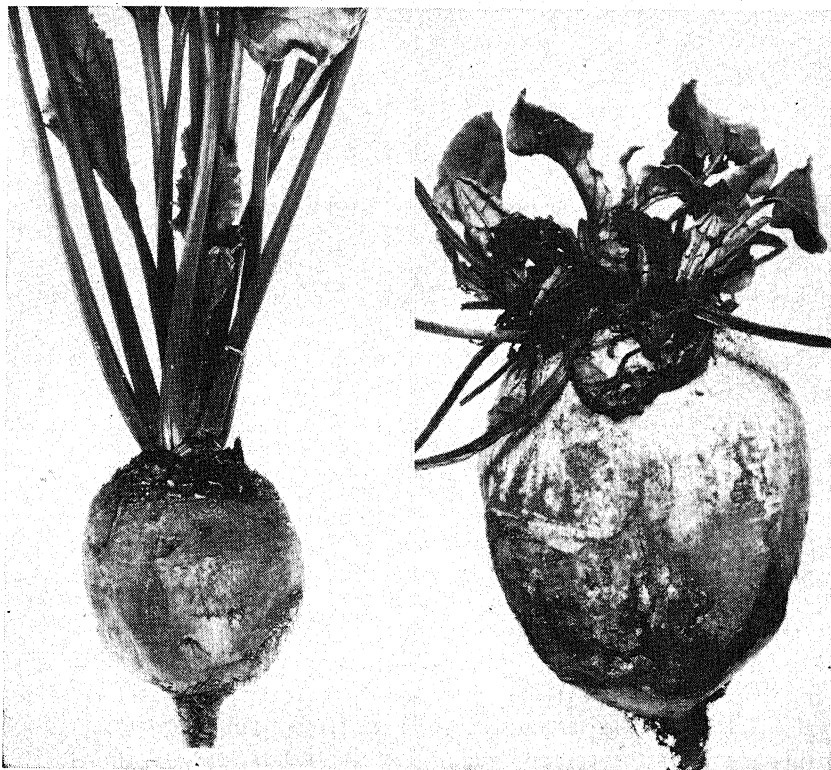
FIG. 7.—External symptoms of boron deficiencies in beets. Left, normal. Right showing abnormal new leaves, and dark rough spots on beet (39). (Courtesy Wisconsin Agricultural Experiment Station.)

Wood ashes contain boron equal to 10 to 29 pounds of borax per ton (19) based on data collected in Vermont and Canada. Wood ashes also contain up to 150 pounds of potash per ton and considerable quantities of lime when they have not been leached.

Deficiencies of zinc, manganese, and copper are associated with the lime content of the soil (8). Zinc deficiency usually occurs in citrus in Florida when the pH is above 6.5. Both manganese and zinc deficiencies occur on alkaline soils, or soils with a pH of 7.5 or higher. Soils containing marl and burned over muck soils are alkaline, and deficiencies of manganese and zinc are frequent on them. Overliming soils of extremely low clay content produces deficiencies of manganese and zinc for citrus in Florida.

The use of acid fertilizers and sulphur sprays may lower the reaction of the soil to pH 5.0 or below, and copper, manganese. and zinc are leached out, and they become deficient. Zinc sprays for citrus trees have been found to be more effective than soil treatment, due to the fixation of zinc in an unavailable form in the soil. Where deficiencies of copper, zinc, and manganese occur on alkaline soils, the deficiencies may be corrected by the addition of sulphur, which lowers the pH unless the soil contains large quantities of marl, in which case the cost of sufficient sulphur for correcting the trouble may be prohibitive. Where deficiencies of copper, manganese and zinc occur on alkaline soils, these elements apparently should be applied in acid-forming fertilizers and drilled. When drilled with acid-forming fertilizers, these elements should stay available to plants much longer than where they are broadcast and mixed with the soil.

Sulphur increases the yield of many crops on alkaline muck soils (12):

Crop	No sulphur	1,000 lbs. sulphur
Onions—bus................	253	662
Potatoes—bus.............	120	207
Carrots—tons.............	26	32
Parsnips—tons............	20	23
Cabbage—tons............	21	22

The pH of the soil was 7.6 before treatment, which resulted from the upper layer of muck being burned off at some previous time. The sulphur lowered the pH and thereby permitted manganese and possibly other elements to become available to the plants.

Cracked stem of celery was almost eliminated and the yield (12) **was trebled by the application of sulphur to a muck soil of pH 7.2:**

| Sulphur applied–lbs. per acre | None | 500 | 1,000 | 2,000 |
| Yield of celery–tons per acre | 5 | 9 | 16 | 18 |

Cracked stem of celery is usually attributed to a deficiency of boron, which suggests that the lowering of the lime content of the soil produced by the sulphur permitted boron to become available to the crops.

The application of sulphur overcame the need for manganese (12):

Crop	Years	Treatment		
		None	1,200 lbs. manganese sulphate	3,500 lbs. sulphur
		Yield per acre		
Spinach—tons.........	5	3.1	6.5	6.9
Onions—bus..........	5	26	200	278
Potatoes—bus........	8	129	249	253

The application of sulphur enabled manganese in the soil to become available to plants by reducing the lime content of the soil. The untreated soil had a pH of 7.8.

Where soils contain too much lime, the excess may be leached out by applying sulphur or aluminum sulphate. One pound of sulphur will leach approximately 3 pounds of lime out of the soil; approximately two pounds of aluminum sulphate is required to leach one pound of

FIG. 8.—Black alkali soil without treatment. Note scant growth of alfalfa. (Courtesy California Agricultral Experiment Station.)

lime out of the soil. Since one pound of sulphur will leach six times as much lime out of the soil as one pound of aluminum sulphate, the use of sulphur for lowering the lime content of soils is usually much more economical than the use of aluminum sulphate. The results are the same in both cases. The sulphur is converted into sulphuric acid by soil microorganisms; aluminum sulphate is broken down in the soil to give aluminum oxide and sulphuric acid. The sulphuric acid combines with the lime to form calcium sulphate, which leaches out of
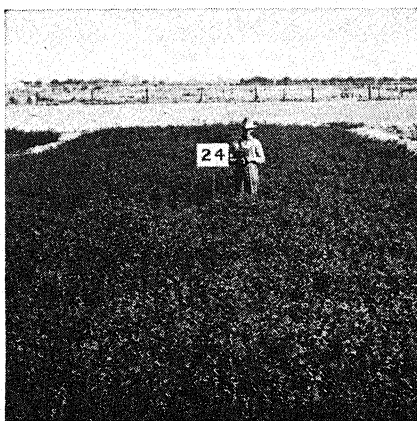
Fig. 9.—The above growth of alfalfa was obtained on black alkali soil 3 years after treatment with 2 tons of sulphur per acre. (Courtesy California Agricultural Experiment Station.)

the soil slowly. The aluminum sulphate has the advantage that it may be applied in solution, while sulphur is insoluble. For flowers, ½ ounce of sulphur or 3 ounces of aluminum sulphate per square yard will take about 900 pounds of lime per acre out of the soil.

The effect of weeds and grass on the lime content of the soil after 30 years was determined by the New Jersey Experiment Station (25). The uncultivated soil contained 5,800 pounds of lime per acre, while the cultivated soil contained only 2,270 pounds of lime per acre. The same amount of lime was applied to both soils during the 30-year period. Under grass and weeds lime accumulated. Lime and organic matter are combined as calcium organic matter, and as the organic matter decreases through decomposition, lime is released to increase the lime content of the clay and other organic matter and thereby increase the lime available for plant growth. When the rate of decomposition of organic matter declines to a low level, after a few years of cultivation, the need for lime is much greater than on new land.

The loss of potash by leaching was much lower on soils which contained a high amount of lime in the subsoil (18) in experiments conducted in North Carolina. The data (Table 20) are in harmony

Table 20.—THE EFFECT OF LIME CONTENT OF THE SUBSOIL ON THE LOSS OF POTASH BY LEACHING.

Lime content of subsoil		Percent of potash leached
Percent acid clay	Percent lime clay	
94	6	76
75	25	58
50	50	52
25	75	22

with the fact that high lime soils usually have more potash which is available to plants than do strongly acid soils. These data also suggest that liming acid soils will reduce the loss of potash by leaching or increase the yield of crops received from a given application of potash.

The use of lime supplies a cheap base which leaches out of the soil instead of potash. The data reported in Table 21 from the Tennessee Agricultural Experiment Station (16) show that lime reduced the loss of potash in the drainage water. The green manure contained 35 pounds of potash per ton which was water soluble. The green manure increased the outgo of potash in the drainage water. The green manure increased

Table 21.—THE EFFECT OF LIME ON THE LOSS OF POTASH BY LEACHING.

Treatment per acre		Pounds of potash	
Lime	Green manure (dry basis)	Leached	Decrease for lime
None	None	59	..
3,570 lbs.	None	48	11
None	2 tons	94	..
3,571 lbs.	2 tons	65	39
None	8 tons	158	..
3,571 lbs.	8 tons	121	38

the nitrate nitrogen which leaches calcium, magnesium, and potash out of the soil. The application of lime reduced the leaching of potash 10 pounds per acre without green manure, 39 pounds with 2 tons, and 38 pounds with 8 tons of green manure.

The effect of the application of lime on the supply of available potash in the soil has received considerable attention with variable

results being obtained. The accumulation or depletion of potash in the soil as a result of liming appears to be as follows:

1. Where potash is added to the soil as potassium chloride or potassium sulphate or in mixtures containing acid elements, liming would increase the possibility of calcium and magnesium leaching out with the acid elements instead of potash, and more available potash would remain in the soil on the clay. The conservation of potash as a result of liming acid soils appears to be greater where fertilizers are drilled in narrow bands.

2. Where liming increases the yield of crops significantly and the seed only is harvested, which contain little potash leaving a larger residue of the stalks and leaves which contain considerable potash, the potash content of the soil may be increased. Where the available potash in the soil is extremely low and the seed only is harvested, the available potash in the soil may be decreased.

3. Where liming increases the yield of crops and the whole plant is harvested, the potash content of the soil is decreased.

4. Where several hundred pounds of lime is applied in the drill with potash-containing fertilizer, the solubility of the potash applied in the fertilizer is decreased, which may reduce crop yields.

The amount of lime used per acre in each state in the United States (33, 37) is reported in Table 22. The Agricultural Adjustment Administration was responsible for the increase in use of lime during the period 1933 to 1944. In 1944 about 15 times as much lime was used as in 1933. In 1936, New Jersey, Massachusetts, and Wisconsin used 100 pounds of lime or more per acre. The following amounts of lime were used per acre of cropland by regions: New England 56, Middle Atlantic 79, Middle Western 54, Southern 18, and Western 4. The amount of lime used in 1944 was about four times as much as was used in 1936.

Regardless of how hard agricultural leaders have worked on liming programs, very little lime has been used. One reason is that farmers as a whole do not have sufficient equipment available to haul and distribute lime; and too, lime is not generally available at local market places. The most successful liming programs have been put across where orders have been taken for lime delivered to the farm, or delivered and distributed on the land. Where lime is hauled by trucks and distributed directly on the land without rehandling, the cost should be considerably less than where it is rehandled. The fact that assignments on Agricultural Adjustment Administration payments for lime

may be made instead of paying cash has stimulated the use of lime, and it probably will influence its use more as time goes on.

The growth of legumes in the rotation indicates the need for lime better than any other method of testing soils for deficiencies of lime. When the growth of alfalfa, lespedeza, vetch, sweet clover, soybeans, or other legumes is unsatisfactory and sufficient phosphorus and potash have been supplied, the need for lime is strongly indicated. However, it should be pointed out that the use of large amounts of superphosphate reduces the need for lime. The presence of sorrel in hay meadows indicates a deficiency of lime. The application of lime to small areas in the field for observations is the most reliable means for determining whether or not crops will respond profitably to lime. It is generally recommended that farmers apply lime to small areas to determine the needs of crops for lime.

Rapid tests for determining the lime needs of the soil are less accurate than field demonstrations, but they are useful for getting a general idea concerning the probable response of crops to lime. There are several tests available which are satisfactory. However, it should be borne in mind that no test other than plant response is entirely satisfactory except where the lime content of the soil is very high or very low. The most commonly used tests for determining the need of crops for lime are dyes in solution. The dyes are applied directly to small amounts of soil and the need for lime is determined by the change in color of the dye. Charts which give an estimate of the amount of lime needed are furnished with these tests.

One of the most extensively used tests for determining the lime requirement of soils is Comber's or, "Rich-or-Poor", which tests for soluble iron. An alcholic solution of potassium thiocyanate is applied to dry soil which is shaken and allowed to settle. In general the more acid the soil is, the more soluble iron (ferric) will be present and the redder the solution. However, all acid soils do not contain soluble iron, and when they do not, the test fails. This test is widely used in the Middle West, but it has been used little in the South.

The glass electrode electric method is the most accurate means of determining the pH of soils from which the amount of lime needed may be estimated. However, the pH determination by this method is more accurate than the estimated amount of lime based upon the test. The use of this method where the electrodes are placed in the soil is the most accurate procedure for determining the pH of soils. Most soil laboratories use the glass electrode for pH determinations at the present time.

Table 22.—The Use of Lime by States, 1929-44.[1]

State and division	1936	1937	1938	1939	1940	1941	1942	1943	1944
	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons
Maine	24,998	39,375	43,375	45,572	58,210	69,144	69,544	64,688	100,257
New Hampshire	5,800	17,800	14,100	18,400	27,200	27,200	27,700	16,269	37,719
Vermont	14,659	34,000	24,191	35,555	51,277	42,000	93,000	68,500	104,735
Massachusetts	34,612	40,041	52,891	57,780	53,550	54,440	59,397	37,467	66,095
Rhode Island	2,829	6,450	6,037	7,194	7,969	9,721	9,053	6,640	9,797
Connecticut	30,975	39,110	35,952	58,050	60,044	60,824	58,920	44,550	70,000
New York	233,274	325,080	341,849	478,442	544,374	698,442	584,443	527,116	791,770
New Jersey	73,938	93,511	105,706	105,104	108,781	106,334	123,290	169,753	214,326
Pennsylvania	307,760	502,317	665,938	705,716	814,374	887,436	1,198,300	1,121,000	1,272,000
North Atlantic	728,845	1,097,684	1,290,039	1,511,813	1,725,779	1,955,541	2,223,647	2,055,983	2,666,699
Ohio	318,959	353,409	318,398	430,914	813,875	1,145,429	1,420,059	1,520,646	1,787,390
Indiana	463,837	574,561	570,080	427,016	949,428	1,000,520	1,276,534	1,264,531	1,167,186
Illinois[2]	1,022,916	1,121,857	1,600,778	1,788,134	2,749,576	2,674,741	3,866,568	3,221,477	3,985,000
Michigan	215,000	265,000	167,000	325,000	325,000	488,000	840,000	515,000	702,000
Wisconsin	682,837	621,494	476,145	395,680	771,029	876,387	1,461,380	1,120,636	1,932,709
Minnesota	40,169	40,793	37,360	44,145	64,762	123,825	339,874	300,000	280,899
Iowa	902,689	432,373	239,929	399,154	1,018,410	1,025,903	1,957,141	1,922,225	1,990,507
Missouri	406,533	375,037	440,411	441,217	1,382,974	1,558,799	1,694,012	1,482,982	1,613,654
Kansas	27,762	55,067	40,206	41,603	46,059	70,347	66,105	142,215	539,600
North Central	4,080,702	3,839,591	3,890,307	4,292,863	8,121,113	8,963,951	12,921,673	11,489,712	13,998,945
Delaware	17,652	23,626	26,532	28,568	29,736	24,732	24,120	34,720	34,000
Maryland	85,304	116,964	100,047	98,592	126,093	129,296	141,303	194,183	228,498
Virginia	196,140	300,000	513,312	709,558	867,552	912,508	1,077,579	1,097,757	817,200
West Virginia	67,248	171,990	225,842	271,830	345,194	361,294	441,690	478,184	512,929
North Carolina	94,254	136,242	144,395	206,287	307,889	372,919	326,888	671,540	600,000
South Carolina	48,166	65,314	64,332	129,421	147,961	110,194	150,000	132,000	508,000
Georgia	16,714	24,332	13,606	24,891	116,096	77,717	80,033	85,000	114,427
Florida	42,748	53,986	41,259	68,771	79,804	58,335	108,645	121,172	60,653
South Atlantic	568,226	892,454	1,129,315	1,537,918	2,020,325	2,046,995	2,350,258	2,814,556	2,875,707

Kentucky	831,439	781,347	868,214	873,249	1,368,930	1,545,630	1,386,479	1,222,325	1,114,802
Tennessee	276,000	447,418	521,400	662,000	900,000	1,165,695	675,000	620,000	1,212,000
Alabama	19,749	45,771	40,409	44,177	129,266	110,712	100,101	225,620	260,026
Mississippi	4,263	6,799	9,648	48,506	11,855	23,227	49,725	64,370	812,781
Arkansas	6,543	30,178	48,828	33,156	57,443	37,354	35,886	61,318	93,432
Louisiana		1,185	2,287	3,862	5,981	5,826	7,122	40,000	300,000
Oklahoma	7,000	10,000	8,500	10,640	12,414	19,318	42,137	55,919	415,562
Texas		4,738	1,566	287	3,439	2,318	2,327	2,870	10,641
South Central	1,144,994	1,327,436	1,503,852	1,675,877	2,489,328	2,910,080	2,298,777	2,292,422	4,219,244
Washington	8,750	8,900	9,195	11,550	12,425	12,000	12,380	17,930	11,005
Oregon	10,020	16,955	25,598	26,250	27,500	18,708	18,574	23,000	26,000
California	24,050	15,987	10,919	9,599	9,515	9,156	12,996	28,890	31,014
Western	42,820	41,842	45,712	47,399	49,440	39,864	43,950	69,820	68,019
United States	6,565,587	7,199,007	7,859,225	9,065,870	14,405,985	15,916,431	19,838,305	18,722,493	23,828,614

United States totals, 1929-35

Year	1929	1930	1931	1932	1933	1934	1935
Tons	3,807,852	3,587,684	2,611,259	1,810,627	1,547,912	2,748,491	3,504,595

[1] Ground limestone and other liming materials converted to ground-limestone basis.
[2] Includes limestone screenings, used in some counties, which is coarser than ground limestone in the usual meaning.
Agricultural Adjustment Agency. Data based on surveys made by State Agricultural College agronomists includes county surveys of producers, and data from County Extension Agents and AAA offices.

The total amount of lime necessary to remove all of the acid (hydrogen) from the clay can be determined by leaching a definite amount of the soil with a salt like calcium acetate (lime vinegar). The calcium goes on the clay, replacing the hydrogen which takes the place of the calcium in the calcium acetate and forms vinegar, which leaches out. Then lime water is added to the solution until the vinegar formed is neutralized. A dye is used which changes color when the vinegar has been neutralized by the lime water. The lime used by the vinegar is the amount needed by the quantity of soil used, from which the lime needed by an acre of soil can be calculated.

Where soil samples are to be sent to a laboratory for lime recommendations, a dozen or more small samples from the field in question should be taken from the surface soil and thoroughly mixed, from which a pint of soil may be sent to the laboratory for testing. The soil may be shipped in tin cans or ice cream cartons, or in containers specially prepared for the purpose. The samples should be carefully labeled. In climates where lime accumulates in the subsoil or slightly below, a sample of the subsoil should also be sent to the laboratory for testing.

SOURCES OF LIME

Lime is leached out of the soil continuously where the rainfall is sufficient to leach through the soil. Where lime accumulates in shallow lakes, the leaching water is probably saturated with lime bicarbonate. When this water goes through the lakes, the growing plants use up part of the carbon dioxide in the bicarbonate of lime, and the lime bicarbonate is converted into lime (calcium carbonate). Since lime is much more insoluble than lime bicarbonate, it settles on the plants and finally falls to the bottom and accumulates. The accumulations are called marl. Marl may be nearly pure lime; most marls which are used for liming purposes contain 50 to 90 per cent lime. The impurities in marl are clay and organic matter. The lime which is carried into the ocean in drainage water is used by plants and in turn by insects which are consumed by fish and shell animals, the remains of which eventually accumulate in beds on the bottom of the ocean. These beds may be nearly pure lime, or they may contain considerable clay. With the changes in the earth's surface which have taken place in the past, land which was once in the ocean has been raised up, and many lime deposits are now above water.

Soil acidity is corrected by the addition of materials to the soil which contain calcium. However, most liming materials contain magnesium as well as calcium. The magnesium content of liming materials

is more valuable than the calcium on soils which are deficient in magnesium. In general, lime should be bought on the basis of the cost of the calcium and magnesium delivered and applied to the land. The chemical properties of calcium and magnesium are similar, and they are closely associated in nature. Even though high-calcium limestone is low in magnesium, ordinarily it contains sufficient magnesium to satisfy the needs of crops for magnesium when the soil is limed.

Where small amounts of lime are used in mixed fertilizers, dolomite increases the yield of cotton more than does high-calcium lime. There are three possible reasons for the superiority of dolomite over high-calcium lime in mixed fertilizers: (a) the dolomite supplies magnesium which is often deficient in soils on which fertilizers containing large quantities of sulphur are used; (b) dolomite is much less soluble than high-calcium limestone and probably permits the phosphate to stay in a soluble form longer, and (c) magnesium sulphate is much more soluble than potassium sulphate, and magnesium will tend to leach out with the sulphur instead of potash. Magnesium sulphate is very soluble in water, and as a result the use of large amounts of superphosphate and sulphate of ammonia causes the loss of large amounts of magnesium in the water leaching through the soil.

Limestone, dolomitic limestone, dolomite, calcium silicate, marble dust, and ground oyster shells are shipped in bulk in open freight cars, and they carry a low freight rate. A car holds 40 tons of these materials. Hydrated lime, burnt lime, and basic slag are commonly packaged and shipped in closed cars which carry a higher freight rate than the above liming materials.

Even though calcium silicate slag is about as soluble in water as limestone, it should be slower acting in the soil. It is much more difficult to overlime with calcium silicate slag than with ground limestone. When the calcium from lime goes on the clay, the carbon dioxide goes into the air, and the clay can take up all of the lime needed; when the calcium from calcium silicate slag goes on the clay, silicic acid is formed, which competes with the clay for the calcium, and as a result the clay takes the calcium up slowly. For this reason farmers in some sections have obtained better results with slags than with limestone where heavy applications of both have been made. Calcium silicate slag contains calcium equal to 80 to 90% pure lime.

Ground limestone as sold on the market usually contains 90% or more of lime. Limestone is mined out of quarries and ground by machinery.

Dolomite contains as high as 45% magnesium carbonate and 55%

or more of calcium carbonate. Due to the fact that 84 pounds of magnesium carbonate has the same power to correct soil acidity as 100 pounds of lime, dolomite may have a purity equal to 100% or more lime.

Burnt lime or quick lime is calcium oxide, and only 56 pounds is required to produce the same results as 100 pounds of lime. Burnt lime is very disagreeable to handle, due to the fact that it will blister the skin, and it is very dangerous if it gets into the eye.

Where limestone outcrops on or near a farm, it may be practicable to burn it, using wood. The effect of burning limestone is to change rock lime into powdered burnt lime. At one time it was believed that burnt lime would burn the organic matter out of the soil, but it has been proven that it produces no such harmful results. When burnt lime comes in contact with the soil water, it is quickly converted into hydrated lime, which readily combines with the carbon dioxide in the soil water to form calcium carbonate. In fact burnt lime has the same effect on the soil as ground limestone. Burned lime may be treated with water to form hydrated lime before it is applied to the soil. Hydrated lime is not as harmful to the ones who apply it as burned lime.

Hydrated lime is produced by adding water to burned lime. Seventy-four pounds of hydrated lime equals to 100 pounds of lime for acid soils. Both hydrated and burned lime are injurious to the skin and eyes. They should be handled with care. When either burned or hydrated lime gets into one's eyes, it should be washed out by pouring a stream of water through the eye with the victim lying on his back. When the lime has been washed out, castor oil or lard should be put into the eye. A doctor should be consulted at once.

Basic slag is produced as a by-product of the iron industry. The iron ore is mixed with limestone and heated to a very high temperature. The calcium in the lime combines with the impurities of the iron ore, which are silica (sand), sulphur, and phosphorus. When the iron is melted the basic slag comes to the top and is removed. The phosphorus content of the basic slag produced in this country runs from 8 to 12%, and the lime content from 70 to 85%. Part of the lime in basic slag is in the form of calcium silicate. It has been found to be a good source of lime and phosphorus for legumes where both are needed. However, basic slag has been inconsistent as a source of phosphorus for cotton.

Blast-furnace slag, ground slag, and granular slag are primarily calcium silicates. Blast-furnace slag is a by-product of the iron industry where the iron ore contains little phosphorus. Ground and granular

slags are by-products obtained on heating rock phosphate with silica at high temperatures to drive off the phosphorus. These materials are hard, appear sandy or glassy, and are slow in correcting acidity. In the production of calcium silicate slags the red hot material is poured into water. It breaks up into small particles approximately the size of bird shot. It takes 116 pounds of pure calcium silicate slag to be equal to 100 pounds of pure limestone.

Livestock should be kept away from calcium silicate slag produced in recovering phosphorus from rock phosphate because, it contains harmful quantities of fluorine. According to the Tennessee Agricultural Experiment Station (17) "farm animals should be kept away from piled slag just as they are from nitrate of soda." Care should be observed so that piles of calcium silicate slag are not left when this material is used to top-dress pastures or other crops on which cattle graze.

Oyster shells contain from 90 to 99% calcium carbonate, and they should give the same results as ground lime except where magnesium is needed. They are nearly pure calcium carbonate.

Sugar beet and paper mill refinery limes are satisfactory, depending upon their lime content. They are used locally.

Gypsum or landplaster is calcium sulphate, and it contains as much acid as lime. It will not correct soil acidity, but it may supply plants with calcium. The use of gypsum will increase the leaching of magnesium, potash, and sodium as sulphates. It is usually not used as such except to spread on the leaves of peanuts in the Southeast. It makes peanuts produce well and develop kernels on soils low in lime, but experimental data show that it is not needed where the soils have been well limed. Superphosphate is about half calcium sulphate.

Superphosphate is not generally used as a liming material, but certain data show that one of its primary benefits on extremely acid soils is due to the calcium which it contains. Superphosphate contains calcium equal to about 50% lime. It should be borne in mind that the calcium in superphosphate is combined with phosphate and sulphur, and it is generally considered that it neither decreases nor increases soil acidity. The high superphosphate requirement of crops on strongly acid soils is attributed partly to the calcium in the superphosphate which is used as a nutrient by crops.

Limestone, dolomitic lime, dolomite and marble dust should be 90% pure lime or higher. Materials of lower pure lime content are equally valuable based upon the actual lime content, but their low lime content handicaps them considerably where they are hauled long distances. Where lime containing 90% pure lime costs $1.00 per ton

at the plant, it may cost $6.00 per ton distributed on the field. The freight and handling costs are the same regardless of purity. On the basis of the estimated cost, a lime of 85% purity is worth only $5.67 in the field or $0.67 per ton at the plant; one of 80% purity is worth $0.33 at the plant; and one of 75% purity has no value at the plant. The lower values for limes of less than 90% purity may prevent their use except locally, since there is sufficient high grade lime available.

The value of different liming materials depends upon their calcium (and magnesium) contents. Most liming materials contain less than 100% lime, and their values are calculated as shown below:

Material	Purity percent	Pounds equal to 2,000 lb. 90% lime	Value per ton at $6.00 per ton for ground lime	Estimated cost per ton
Ground lime......	90	2,000	$6.00	$6.00
Burned lime......	83.3	1,210	9.93	30.00
Hydrated lime....	87	1,530	7.80	20.00
Dolomite........	95	1,900	6.33	6.00

SOIL ACIDITY

The clay particles become loaded with hydrogen when all of the calcium, magnesium, potassium, and sodium have leached out of the soil. When the clay is loaded with hydrogen, it is called hydrogen clay. When it is loaded with calcium, magnesium, potassium, sodium, or hydrogen, it is called calcium clay, magnesium clay, potassium clay, sodium clay, and hydrogen clay.

An element on the clay particles can not be removed without another element taking its place. The presence of a high amount of hydrogen on the clay indicates a low amount of the desirable nutrients: calcium, magnesium, potash, and soda.

Water is composed of oxygen and hydrogen. Since carbon dioxide and water are always present, hydrogen is always available to replace any element which goes off of the clay into the soil water. When the place of hydrogen on the clay is taken by calcium (or other elements), the hydrogen combines with the elements associated with the calcium and forms water. Hydrogen is, therefore, available to replace other elements at any time, and it disappears, when another element takes its place on the clay.

The amount of hydrogen in 1,000 pounds of soil water normally varies from 0.000,000,01 to 0.0001 pounds. The latter figure is 10,000 times as large as the former. Since the actual amount of hydrogen in

the soil water is so small, and the relative difference is so great, the amount of hydrogen is expressed by the symbol pH. The procedure of calculating the pH of a soil solution is illustrated in the following table:

Column 1	Column 2	Column 3	Column 4
Pounds of hydrogen in 1000 pounds of water	One divided by pounds of hydrogen in 1000 lb. water	Power of 10 to give numbers in column 2	pH
0.00000001	100,000,000	8	8.0
0.00000010	10,000,000	7	7.0
0.00000100	1,000,000	6	6.0
0.00001000	100,000	5	5.0
0.00010000	10,000	4	4.0

The hydrogen which is used in calculating pH is only that which has been separated from water. The pounds of hydrogen in 1,000 pounds of water is determined by means of dyes or by means of electrical equipment.

The pounds of hydrogen in 1,000 pounds of water usually varies from 0.000,000,01 to 0.000,100,00 pounds (Column 1). Since these numbers are exceedingly small decimal fractions their use to express acidity is not easily kept in mind. Their use to express acidity was first simplified by dividing them into one. These numbers are exceedingly large (Column 2). The expression of acidity was further simplified by expressing the large number as the power of 10 to give the number (Column 3) and is called pH (Column 4).

As an illustration of the method of calculating pH:

1. The amount of hydrogen in 1,000 pounds of water is found to be 0.0001 pounds (Column 1)
2. Dividing: 1/0.0001 = 10,000 (Column 2)
3. The power of 10 to give 10,000 is 4 (Column 3). (The power of 10 to give any number may be looked up in logarithm tables).
4. The pH of the solution is 4.0 (Column 4).

The pH of the soil solution is qualitative and does not refer to the total amount of hydrogen on the clay. The relative amount of hydrogen clay and lime clay in soils of different pH has been estimated[1] as follows:

[1]Personal communication—N.J.Volk.

pH	Per cent lime clay[1]	Per cent acid clay[2]
4.0	0	100
5.5	25	75
6.0	50	50
7.0	75	25
8.0	100	0

[1]Including magnesium, potash, and soda clay.
[2]Hydrogen clay.

The soil solution equalizes itself with the clay. At pH 8.0 no hydrogen exists on the clay, and the clay is all calcium clay, magnesium clay, potassium clay, and sodium clay, while at about pH 4.0 the clay is all hydrogen clay.

The calcium, magnesium, potash, and soda on the clay are not easily leached out by pure water; these elements which are in the soil water are lost by leaching. The presence of carbon dioxide in the soil water increases their loss by leaching. The soil water probably always has all of the carbon dioxide that it will hold, and there is nothing which can be done to lessen its influence. Of much more inportance for consideration in the leaching of these elements is sulphur, chlorine, and nitrate nitrogen. The sulphur and chlorine in fertilizers should be reduced to the minimum requirement of crops in so far as practicable.

The importance of clay as storehouse for plant nutrients is illustrated by the fact that at a pH of 4.0 the soil water of an acre of soil containing 25% water can be neutralized with 2½ pounds of lime, while many soils require more than 5,000 pounds of lime per acre to neutralize the acid on the clay. The clay holds most of the calcium, magnesium, potash and soda out of the soil solution and lets them go into solution as small amounts of these elements are taken out of the solution by growing plants or by leaching.

The low quantity of lime required to change the pH of the soil water is illustrated by calculating the amount of lime required to change the pH of the soil water of 2,000,000 pounds of soil (one acre) containing 25% water from pH 4.0 to pH 8.0:

1. Multiplying, 2,000,000 x 25% = 500,000 pounds of water present.
2. Dividing, 500,000 ÷ 1000 = 500 (number of 1,000 pounds of water).
3. Subtracting
   0.00010000 = pounds hydrogen ions in 1000 pounds water at pH 4.0.
   0.00000001 = pounds hydrogen ions in 1000 water at pH 8.0.
   _____
   0.00009999 = pounds hydrogen ions lost in 1000 pounds of water in going from pH 4.0 to pH 8.0.

4. Multiplying 0.00009999 by 500 (2 above) gives 0.05 pounds of hydrogen ions lost from the soil water of an acre of soil in going from pH 4.0 to pH 8.0. (50 pounds of lime will replace 1 pound of hydrogen). Multiplying 0.05 x 50 gives 2.5 pounds of lime required to change the pH of the soil water of an acre of soil containing 25% water from pH 4.0 to pH 8.0.

In the absence of acids other than clay acid, where a soil requires 5,000 pounds of lime to change it from pH 4.0 to 8.0, the clay takes up 2,000 times as much lime as the soil water. The presence of the acid radicals and elements, sulphate, carbonate, chloride, and nitrate, increases the amount of calcium, magnesium, soda, and potash in the soil solution. The elements in solution are subject to leaching, and are lost when water leaches through the soil. The clay, therefore, serves as a storehouse for certain of the plant nutrients.

The quantity of calcium, magnesium, potash, and soda in a good crop is many times the quantity found in the soil solution at any one time. When plants remove a part of the nutrients which are in the soil solution, it is almost completely replaced from the supply on the clay. The clay has the property of combining with the calcium, magnesium, potassium, ammonia, and sodium, in which form they are not lost readily from the soil, and the clay thereby maintains the supply in the soil water at an almost constant level.

SUMMARY AND CONCLUSIONS

The data reviewed on the use of lime show that:
1. Lime increases the yield of most crops on acid soils.
2. Superphosphate supplies both lime and phosphate.
3. The use of lime reduces the amount of phosphate and potash necessary for crop production.
4. Dolomite is apparently the preferred form of lime in areas where fertilizers containing large amounts of sulphate are used.
5. The use of too much lime on strongly acid soils will produce over-liming injury.
6. The use of 5 pounds of borax per ton of lime will prevent or overcome over-liming injury.
7. Overliming injury is not produced as often with calcium silicate slag as with other sources of lime.

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The Response of Crops and Soils to Phosphorus

Phosphorus is the most deficient element where rotations, including green manures and hay crops, are used.

The first phosphorus applied to soils came from the bones of animals, which contain approximately 50% bone phosphate of lime, or 23% phosphate. The quality of raw rock phosphate is still expressed as bone phosphate of lime by the fertilizer industry. Phosphorus is sold in the fertilizer trade as phosphate or phosphoric acid. Phosphoric acid is 44% phosphorus.

The phosphorus in the bones of animals is obtained from the food they eat. Animals grown on phosphorus-rich soil have larger bones and normally grow to a larger size than those grown on soil low in phosphorus. When the feed for cattle is low in phosphorus, they chew leather and bones, and in general they have an unthrifty appearance.

Fertile soils may contain as much as 5,000 to 10,000 pounds of phosphate per acre to a depth of 6 2/3 inches; however, most soils contain considerably less than 5,000 pounds; large areas contain less than 1,000 pounds per acre (17)[1]. Most of the phosphorus in the soil is in a form which is not available to plants. Small amounts of the phosphorus in the soil become available for plant use continuously. The rate at which phosphorus becomes available to plants is too slow to supply the needs of crops on most soils. Since phosphorus exists in the soil in a rather insoluble form very little of it leaches out; however, small amounts of phosphorus do leach continuously. The phosphorus which leaches out of the soil goes into streams and accumulates in the ocean. In comparison to other soils, coastal plains soils, which were in the ocean at one time, are very low in both total and available phosphorus, which suggests that the ocean water extracted the phosphorus from the soil while it was on the floor of the ocean.

1 Numbers in parenthesis refer to the source of information, page 298.

The phosphorus in the ocean waters is consumed by water plants. The water plants are consumed by insects, fish, and shell animals, which in turn are consumed by larger fish, etc. Some fish are eaten by birds; others die and go to the bottom of the ocean, where their bones accumulate with shells and other skeletons. Where fish are eaten by birds, large deposits of manure accumulate on islands where they congregate. Guano, which is bird manure, is used to supply phosphorus as well as other fertilizing elements to a small extent. Over long periods of time the manure on the islands may decompose, leaving residues high in lime and phosphate.

In the course of long periods of time, land once in the ocean is lifted up out of the water, while land out of water becomes submerged again. Upon exposure of a bed of lime containing phosphate to the weather, the limestone dissolves out, leaving the more insoluble rock phosphate as a residue. Beds of rock phosphate have resisted weathering for ages.

Rock phosphate is a compound of calcium, phosphorus, oxygen and fluorine. It should have a fluorine content of approximately 4%; actually, it may have as much as 6%. The fluorine in rock phosphate makes the phosphorus much more insoluble than it would be without it. The insolubility which enabled rock phosphate to resist weathering for thousands of years makes it almost unavailable for most crops when applied to the land. Rock phosphate used for making superphosphate contains 33 to 35% phosphate.

The rock phosphate mined, exported, imported, and consumed in the United States in 1939 (13) was as follows:

	Tons
Mined...	3,987,970
Imported..	3,500
Exported..	949,006
Consumed in United States....................	2,811,561

Approximately one-fourth of the rock phosphate mined in the United States was shipped to foreign countries. The rock phosphate consumed in the United States is used largely for making superphosphate.

The phosphate reserves of the United States (13) were estimated in 1940 to be 13,291,543,000 long tons, with 5,306,651,000 tons in the eastern states (mainly Florida and Tennessee), and 7,984,892,000 tons in the western states. The greater part of the phosphate used in this country is mined in Florida, where the known deposits are estimated at 2,000,000,000 tons, with total estimates running to 5,000,000,000 tons. Apparently the phosphate deposits in Florida should last this
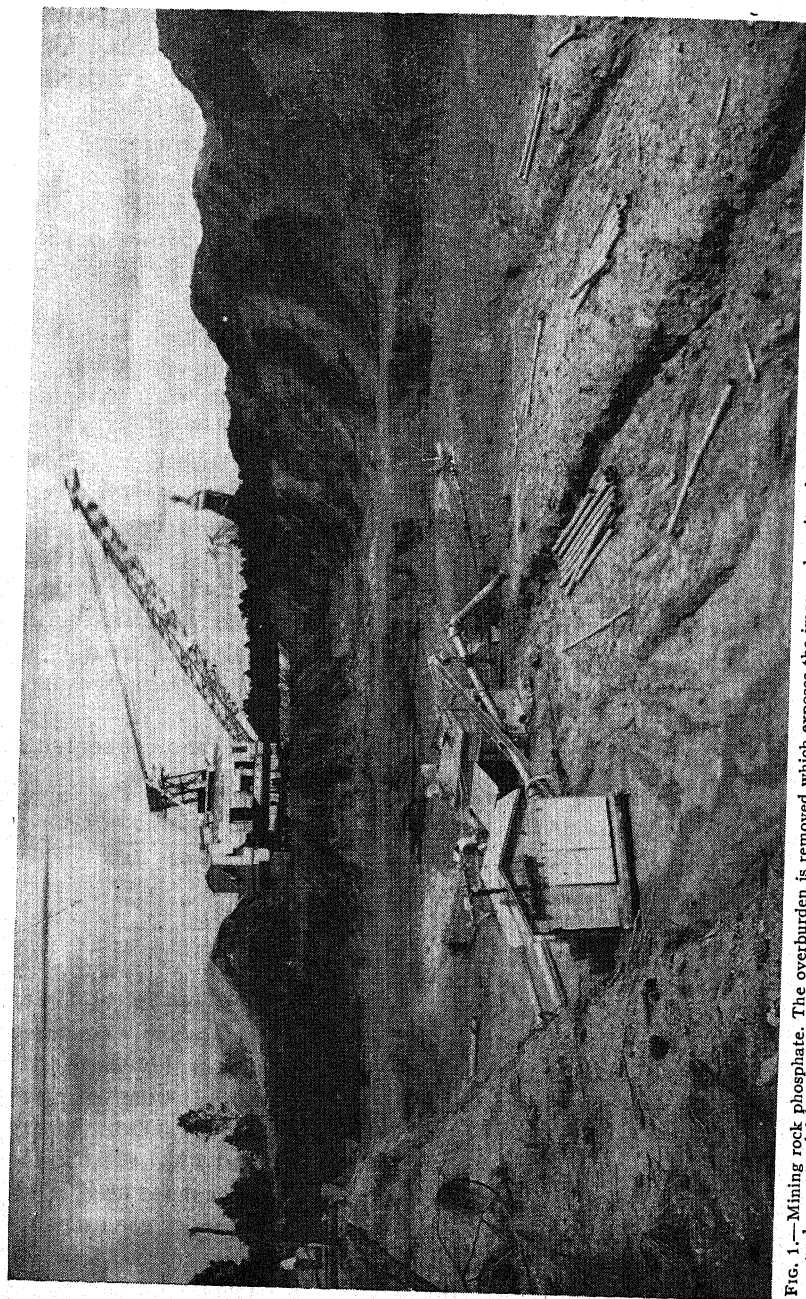
FIG. 1.—Mining rock phosphate. The overburden is removed which exposes the impure deposits of rock phosphate. The rock phosphate mixture is broken up by a powerful force of water, and is sucked up and transported to the separators and washers. (Courtesy International Minerals and Chemical Corporation.)

country 700 years at the present rate of consumption if all the phosphate rock consumed were mined in Florida.

Superphosphate is made by treating rock phosphate with sulphuric acid. Approximately equal weights of finely ground rock phosphate and sulphuric acid are mixed together at the top of tall concrete dens which resemble silos. The mixture is dropped into the den, where the acid changes the insoluble phosphate into a soluble form. The acid takes two-thirds of the calcium out of the phosphate compound, leaving the phosphate in a readily available form.
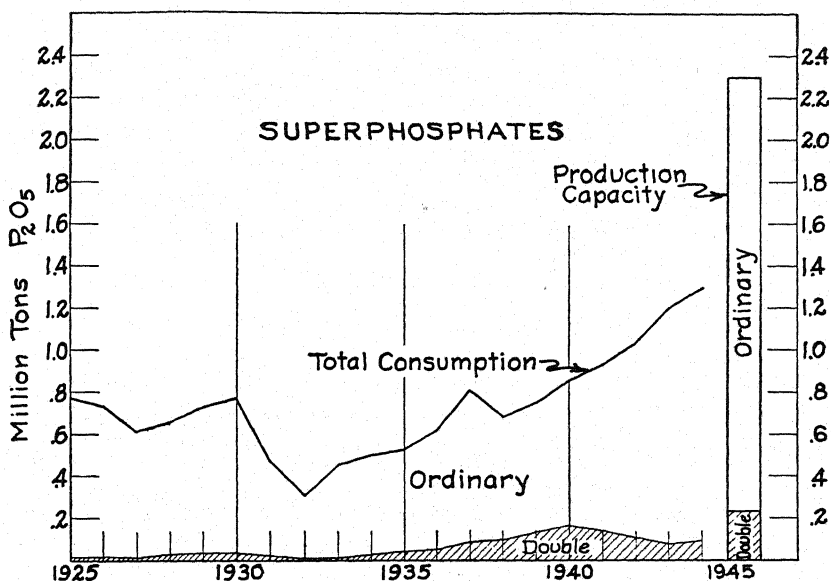
FIG. 2.—The consumption of phosphorus in the United States. (Courtesy U.S.D.A.)

Superphosphate is left in the den until most of the sulphuric acid is used up, after which it is stored in a pile until all the acid is used up. This is called curing. The calcium sulphate formed in the process combines with the free water in the superphosphate and converts it into a crystalline form which is not wet, and as a result the superphosphate becomes dry. During the curing process superphosphate sets up into a hard mass. After superphosphate is cured, it is ground and screened for use in mixed fertilizers or for direct use. If it is completely cured, it stays in good physical condition. Where superphosphate is shipped before all of the acid is used up, it becomes hard before it

reaches its destination. Regular superphosphate is primarily a mixture of monocalcium phosphate and calcium sulphate.

The time necessary to make superphosphate may be reduced by using an excess of sulphuric acid. The additional sulphuric acid reacts with monocalcium phosphate to form free phosphoric acid and more calcium sulphate. Free phosphoric acid makes superphosphate sticky and decomposes fertilizer bags. The free phosphoric acid may be neutralized with lime or ammonia.

Most run-of-pile superphosphate contains 18 to 19% phosphate (phosphoric acid) as it is made. The 18% grade superphosphate is shipped as it is produced in the plant except that a small amount of dolomite may be added to neutralize the free acid. Sixteen per cent superphosphate may be made by diluting 18% superphosphate with dolomite or sand; 20% superphosphate is made by adding triple superphosphate to 18% superphosphate. The addition of sand to superphosphate can not be justified; the addition of triple superphosphate to 18% superphosphate to make 20% superphosphate is too small a change to be economical, except where additional phosphate is needed for legal standards. It would be logical and cheaper to sell run-of-pile superphosphate on the basis of analysis without additions of other materials.

Phosphoric acid may be produced by the addition of sufficient sulphuric acid to rock phosphate to convert all of the calcium into calcium sulphate. Phosphoric acid is soluble in water. Calcium sulphate is almost insoluble in water. The phosphoric acid may be dissolved in water and separated from calcium sulphate by filtering.

The element phosphorus may be obtained by heating rock phosphate (2,700°C.) with coke and silica gravel (41). The coke takes the oxygen away from the rock phosphate forming the poisonous gas, carbon monoxide; the silica takes the calcium away from the phosphate, forming calcium silicate slag, and the element phosphorus goes off as a vapor. The phosphorus vapor is recovered, cooled and condensed to a liquid, which is stored in tanks. For fertilizer purposes phosphorus is burned, after which it is passed into a spray of water which converts it into phosphoric acid.

Triple superphosphate, often called concentrated superphosphate, is made by treating rock phosphate with phosphoric acid (41). The phosphoric acid takes two-thirds of the calcium out of the rock phosphate and nearly pure mono-calcium phosphate is formed. The curing of triple superphosphate is similar to that of superphosphate. Triple superphosphate differs from regular superphosphate in that it is not

diluted with calcium sulphate. Triple superphosphate contains approximately 45% phosphate (phosphoric acid).

Ammonium phosphate is made by passing ammonia into phosphoric acid. Ammonium phosphate usually has one ammonia combined with one phosphoric acid and is called ammonium phosphate. Two ammonias may be combined with one phosphoric acid, and the product is called di-ammonium phosphate. Ammonium phosphate contains 11%
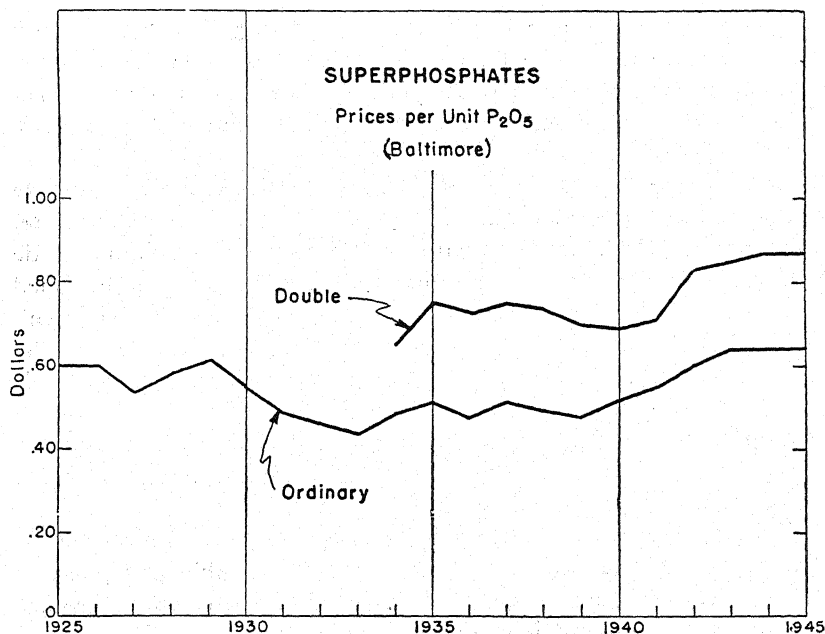
FIG. 3.—Wholesale price of 20 lbs. of phosphate (P₂O₅) at Baltimore, Maryland. (Courtesy U.S.D.A.)

nitrogen and 48% phosphate. Di-ammonium phosphate contains approximately 21% nitrogen and 53% phosphate.

Dicalcium phosphate is made by treating limestone with phosphoric acid (41). It differs from monocalcium phosphate in superphosphate in that two calciums are combined with two phosphates instead of one. It contains approximately 40% phosphate.

Calcium metaphosphate is made by burning phosphorus in the presence of rock phosphate (41). The burning phosphorus takes two-thirds of the calcium out of the rock phosphate. At high temperatures calcium metaphosphate is a liquid. It cools to a glassy solid which contains 62 to 64% phosphate. It is finely ground before being used as

a fertilizer. Calcium metaphosphate is the same chemical compound as monocalcium phosphate in superphosphate with two waters (molecules) taken out. When calcium metaphosphate is applied to the soil, it takes up two waters to form monocalcium phosphate, which is the form in which phosphorus exists in superphosphate.

Potassium metaphosphate is made by burning phosphorus in the presence of muriate of potash. The chlorine may be recovered for industrial use.

Fused rock phosphate is produced by heating silica gravel with rock phosphate (41). The fluorine is reduced to a low level in the process. It has been suggested (20) that fused rock phosphate is essentially a mixture of alpha tricalcium phosphate and rock phosphate (apatite).

Tricalcium phosphate is formed on ammoniation of superphosphate when more than about 2% ammonia is added to 18% superphosphate. In the process tricalcium phosphate combines with the calcium fluoride to form new rock phosphate. The amount of new rock phosphate formed increases with increasing amounts of ammonia. The addition of sulphuric acid to rock phosphate makes the phosphorus water soluble; the addition of ammonia to superphosphate changes water-soluble phosphate to phosphates which are insoluble in water.

Basic slag contains about 75% lime and 8 to 12% phosphate. The phosphate is present as a basic calcium phosphate, the exact composition of which is unknown.

The application of lime to acid soils converts soluble phosphate to calcium phosphates; on strongly acid soils soluble phosphate is changed into iron and aluminum and clay phosphates which are less available than monocalcium and dicalcium phosphates. Where lime is applied to strongly acid soils, the iron and aluminum, and clay phosphates present are not converted into calcium phosphates directly. However, when plants use some of the phosphorus from iron and aluminum and calcium phosphates, the phosphate given up on decomposition of the organic matter is converted into calcium phosphates rather than into iron and aluminum phosphates. When lime is used on strongly acid soils, the phosphate returned to the soil in crop residues or commercial fertilizers is therefore maintained in a more available form than if the soil had not been limed.

Phosphate applied to limed soil is more soluble in weak acid than phosphate applied to acid soil. The per cent of applied phosphate which was extracted with a weak acid (10) from limed and unlimed soil was as follows (Sweden):

	Unlimed soil pH 5.9	Limed soil
	Percent of applied phosphorus soluble in weak acid	
Smallest rate of phosphate..............	2.5	12.5
Intermediate rate of phosphate..........	2.5	12.5
Highest rate of phosphate..............	3.3	25.0

The above difference in weak acid soluble phosphorus was obtained after the lime and phosphate had increased the yield of crops considerably.

Colloidal phosphate, calphos, vitaloids, and longphoska are mixtures of finely divided rock phosphate and clay. These phosphates are washed out of the phosphates which are used for making superphosphate. They are designated as waste pond phosphates. The low content of phosphate and the high content of iron and aluminum in some of these phosphates make them unsuitable for the manufacture of superphosphate. These products contain only about 20% phosphate, which indicates the presence of high amounts of ordinary clay and other

Table 1.—THE RESPONSE OF CROPS TO ROCK PHOSPHATE AND SUPERPHOSPHATE.

Crops	Kind of phosphate	Average per acre				
		Increase in yield	Rate per acre	Value of increase	Cost of fertilizer	Profit or loss
		Bushels	Pounds	Dollars	Dollars	Dollars
Corn 36 tests	Superphosphate	5.49	190	2.95	1.52	1.43
	Rock phosphate	4.65	532	2.52	1.86	0.66
Wheat 33 tests	Superphosphate	4.31	190	4.63	1.52	3.11
	Rock phosphate	1.91	532	2.12	1.86	0.26
		Pounds				
Legume hay 9 tests	Superphosphate	320	190	1.60	1.52	0.08
	Rock phosphate	95	532	0.47	1.86	−1.39
		Bushels				
Potatoes 4 tests	Superphosphate	29.4	500	14.70	4.00	10.70
	Rock phosphate	11.6	1000	5.80	3.50	2.30
Average of the 82 tests	Superphosphate	....	205	4.06	1.64	2.42
	Rock phosphate	....	545	2.29	1.91	0.38

impurities. The clay in these phosphates, as well as that in the soil, is colloidal. The value of the clay in colloidal phosphate is no more than that of an equal amount of clay which exists in the soil. Most soils contain 100,000 to 500,000 pounds of clay per acre to a depth of 6 2/3 inches.

In general the response of crops to rock phosphate is much less than to an equal value of superphosphate. The average of the results from 82 tests in Indiana (47) show that superphosphate made 6 times as much profit as 2½ times as much phosphorus in rock phosphate (Table 1). A change from the use of soluble source of phosphorus should be made only on the basis of data which show that the new source has high value for the specific purpose for which it is to be used.

Sweet clover is a plant which uses rock phosphate well. In Oklahoma (12) rock phosphate applied in 42-inch rows with the seed was as effective as superphosphate for sweet clover production. Good yields of sweet clover were produced when either 200 pounds of finely ground rock phosphate or 200 pounds of superphosphate was applied with 400 pounds of lime in the drill in 42-inch rows.

The response of cotton to rock phosphate and waste pond phosphate is shown by the the following increases in yield on limed soil in Mississippi[1]:

Treatment	Increase in yield— lbs. seed cotton per acre
Superphosphate	131
Colloidal phosphate	−7
Finely ground rock phosphate	5

Colloidal phosphate increased the yield of seed cotton only 17 pounds per acre where superphosphate increased the yield 89 pounds per acre in Georgia (7).

The use of calphos, which is one trade name for waste pond rock phosphate, on vetch and pastures was investigated by the Mississippi Experiment Station. The fertilizers were used at approximately the same cost per acre. The unpublished data from 4 tests are as follows:

[1]Unpublished.

| Treatment | Increase in yield—pounds green weight per acre | | | |
| | Vetch | | | Pasture grass |
	Test 1	Test 2	Test 3	
500 lbs. basic slag............	5,136	1,655[1]	5,580	7,259
200 lbs. superphosphate (20%).	3,888	1,258	.....	4,065
200 lbs. superphosphate, 400 lbs. lime................	.....	.....	4,092	.....
400 lbs. calphos.............	2,256	264	2,604	3,145

[1]Only 400 # basic slag used in this test.

Basic slag made higher increases in yield of vetch and pasture grasses than did superphosphate. Superphosphate made excellent increases in yield of both. The increases in yield produced by calphos when applied at the same cost per acre as the other two materials was only about half as much as was produced by superphosphate and basic slag. If

FIG. 4.—Vetch: basic slag on right; colloidal phosphate on left (44).

rock phosphate were sold to farmers for one-fourth to one-third its present cost, there might be a use for it, but with its present cost it is more expensive than other sources of phosphorus.

The effect of waste pond phosphate, rock phosphate, and super-phosphate on the yield of various crops in Alabama (43) is shown by data in Tables 2 and 3. Other data reported by the Alabama Agri-cultural Experiment Station from greenhouse tests show that waste pond phosphate and rock phosphate have about the same crop pro-ducing value and that eight times as much phosphate in waste pond

Table 2.—Increased Yields in Pounds of Green Weight Per Acre of Vetch and Sorghum from Experimental Plots Fertilized with Different Kinds of Phosphate.

Treatment	Phosphate per acre	Cecil clay		Decatur clay	
		Vetch	Sorghum	Vetch	Sorghum
	Pounds	Yield—pounds per acre			
Superphosphate.......	36	11,883	13,940	10,646	9,316
Waste pond phosphate.	36	4,311	4,893	1,803	2,753
Waste pond phosphate.	72	4,811	9,199	4,299	3,693
Rock phosphate.......	36	4,819	9,859	5,100	4,903
Rock phosphate.......	72	7,463	10,312	8,530	5,927

or rock phosphate was not equal to 200 pounds of 18% superphosphate for the production of crops. The data show that superphosphate made several times as much increase in yield as waste pond or rock phosphate. Superphosphate produced 101, 189, 114, 67, 101, and 160 or an average of 122 pounds more seed cotton than double the amount of phosphate in rock phosphate. The cost of phosphorus in superphosphate is usually about twice its cost in waste pond or rock phosphate, and the cost per acre was about the same where twice as much phosphate was applied in rock phosphate as in superphosphate. The value of 122 pounds of seed cotton at 5 cents per pound is $6.10. With approximately $3.00 per acre invested in both rock phosphate and superphos-

Table 3.—Average Increased or Decreased Yields of Different Crops from Superphosphate, Waste Pond, and Rock Phosphate. 1930-1941.

Source of phosphorus	Phosphate per acre	Prattville Experiment Field			Wiregrass Experiment Sub-station			Tennessee Valley Experiment Sub-station			Monroeville Experiment Field	
		Seed cotton	Corn	Vetch	Seed cotton	Corn	Austrian peas	Seed cotton	Corn	Vetch	Seed cotton	Corn
	Lbs.	Lbs.	Bus.	Bus.	Lbs.	Bus.	Lbs.	Lbs.	Bus.	Lbs.	Lbs.	Bus.
		Two-year rotation of cotton and corn with legumes										
16% superphosphate........	48	110	5.6	5,350	156	3.7	3,037	448	6.9	7,539	.....	.....
Rock phosphate.	48	18	3.2	2,098	−16	−1.1	600	180	4.2	3,663	.....	.....
Rock phosphate.	99	9	2.7	2,556	−33	−1.0	820	334	7.1	5,381	.....	.....
Waste pond phosphate....	48	−6	2.6	2,578	−45	−2.6	268	194	3.4	2,773	.....	.....
		Two-year rotation of cotton and corn										
16% superphosphate........	48	.....	.....	....	89	1.7	....	470	5.4	....	268	1.7
Rock phosphate.	48	.....	.....	....	−2	1.1	....	245	2.9	....	74	−0.3
Rock phosphate.	99	.....	.....	....	22	1.0	....	369	5.5	....	108	1.1
Waste pond phosphate....	48	.....	.....	....	47	1.7	....	239	3.3	....	64	0.0

FIG. 5.—Small grains require phosphate on many
soils in Tennessee. (Courtesy Tennessee Agri-
cultural Extension Service.)

phate, superphosphate made $6.10 more cotton than rock phosphate.
Rock phosphate and waste pond phosphate produced about the same
increase in yield. Waste pond phosphate is sold under the trade names
calphos, longphoska, colloidal phosphate, vitaloids and possibly others.

The effect of lime on the pH and available phosphorus on Norfolk
fine sand in Florida is shown by the data (29) in Table 4. The data
show that the application of small amounts of lime resulted in rather
large increases in pH until it was increased to pH 6.20, after which
heavy application of lime increased the pH only a small amount. The
available phosphate increased with increasing pH until pH 7.0 was
reached, and with the addition of more lime, the available phosphate
decreased. The most desirable pH from the standpoint of available
phosphorus is usually considered to be pH 6.0 to 6.5. On more acid
soils phosphate is tied up as iron and aluminum and clay phosphates.

Table 4.—THE EFFECT OF THREE ANNUAL APPLICATIONS OF LIME ON pH AND
AVAILABLE PHOSPHATE ON NORFOLK FINE SAND.

Pounds of lime per acre in 3 years	pH	Available phosphate— pounds per acre
None	4.85	515
600	5.30	584
1,200	5.50	687
2,400	6.20	806
4,800	6.85	767
9,600	7.00	916
19,200	7.15	721

On soils containing more lime, the phosphate is tied up as new rock phosphate.

Recent investigations show that the most desirable pH of the soil for the growth of crops varies with the type of clay. It is reasonable to anticipate that the lime content of different clays, as expressed by pH, which is most favorable for maintaining the phosphorus in the most available form, would also be different with the different types of clay.

The percentage recovery of applied phosphorus in crops is very low. The application of 60 pounds phosphate per acre in Alabama in 543 experiments (49, 50) resulted in an average increase in yield of seed cotton of 241 pounds per acre. The 241 pounds of seed cotton removed about 2.4 pounds of phosphate or 4% of that applied. In many cases where cotton has been fertilized well for several years, phosphorus can be left out of the fertilizer for a year or two without the yield declining seriously. In Mississippi the residual effect of 32 pounds of phosphate annually for six years (2) increased the yield 179 pounds of seed cotton per acre on the seventh year when no phosphate was applied (average of 5 tests). In one of the tests the residual phosphate increased the 6-year average yield 132 pounds of seed cotton, and 264 pounds on the sixth year.[1]

The recovery of phosphate in greenhouse tests where the roots as well as the tops were harvested in Kentucky (14) was:

	Percent of phosphorus applied in 1936 recovered
Wheat 1936-1937..........................	32
Korean lespedeza 1937.....................	15
Wheat 1937-1938..........................	10
Rye grass 1938-1939.......................	5
Total........................	62

The recovery of nutrients in crops under greenhouse conditions, where other nutrients and water are not limiting factors in crop growth, is much higher than is obtained under field conditions.

The recovery of phosphorus applied in field tests in Ohio (5) was 12.3% the first year, 8.9% the second year, and 7.1% the third year, or a total of 28.3% in three years. Clover used the phosphorus after it had been applied for one year better than did corn and wheat.

The recovery of phosphorus on soils very low in phosphorus in

[1] Unpublished data of J. L. Anthony.
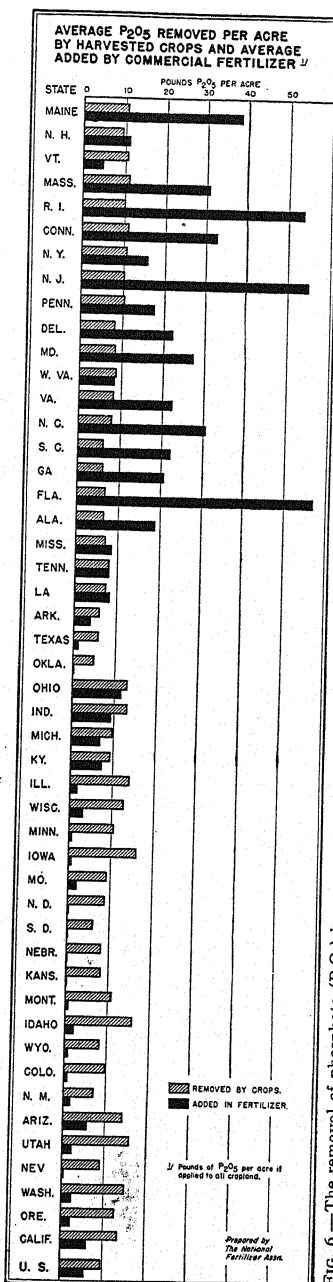
FIG. 6.—The removal of phosphate (P_2O_5) in crops as compared to that supplied by fertilizers. (Smalley, H. R.) The phosphate problem is complicated by many factors. The Fertilizer Review, No. 3, 1940.

England (37) was hay 25%, barley 19%, and wheat 14% of that applied. On soils with more available phosphorus, 24% of one application was recovered by Swedes over a 4-year period. The recoveries were 32% in 4 years, 31% in 5 years, and 34% in 5 years in experiments where grass was cut several times during the year. Most of the phosphorus was recovered in the first two years, and very little was recovered during the fourth and fifth years.

The data presented show that cultivated crops recover from 4 to 34% of the phosphorus applied. Hay crops recover higher percentages of the applied phosphorus than do other crops. It appears that, even with hay crops, it is necessary to apply three to four times as much phosphate as crops remove in order to maintain crop yields.

The phosphorus applied in fertilizers and removed in harvested crops in 1943 is shown in Figure 4. That returned in manure is not shown in the calculation which would influence the data considerably where most of the feed produced is consumed on the farm. If proper credit were given to the phosphorus returned in manure, most of the States east of the Mississippi river apply much more phosphorus than is lost through cropping. These data as well as those presented above show that only a very small percentage of the applied phosphorus is recovered by crops.

Superphosphate applied to soils low in phosphorus often increases earliness in crops (Figure 7). In North Carolina (48) a 4.12-10-3 fertilizer produced 7% more of the total seed cotton in the first picking than nitrogen and potash alone on Piedmont soils; on Coastal Plains soils a 3.3-6-4 fertilizer produced 8% more seed cotton in the first
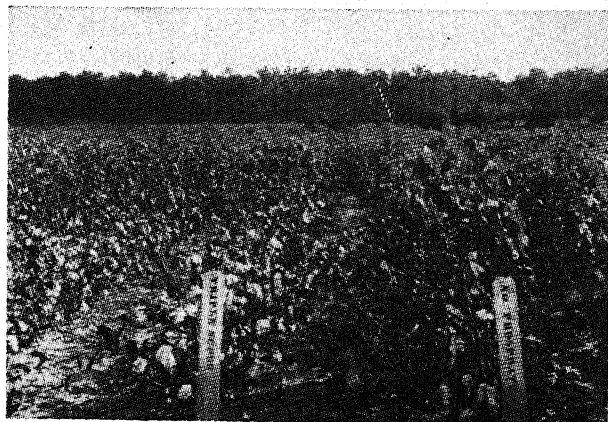
Fig. 7.—Phosphorus (left) increased earliness in cotton (27).

picking than nitrogen and potash without phosphorus. The effects of phosphate on earliness of cotton is of primary importance on wet years when boll weevils are bad.

The effect of fertilizers on earliness of cotton is shown by the unpublished data from Mississippi reported in Table 5. Where phosphorus

Table 5.—THE EFFECT OF FERTILIZERS ON EARLINESS IN COTTON.

Soil badly deficient in phosphorus			Soil with normal response to fertilizer		
Fertilizer, 600 lbs. per acre	Increase of total yield in first picking	Increase in yield per acre due to fertilizer	Fertilizer, 600 lbs. per acre	Increase of total yield in first picking	Increase in yield per acre due to fertilizer
Analysis	Percent	Pounds	Analysis	Percent	Pounds
8-0-0	−2.4	8	6-0-0	12.6	374
8-4-0	16.5	318	6-8-0	23.3	559
8-8-0	19.1	380	6-8-4	17.6	627
			6-8-8	16.4	658
			6-4-4	15.7	545
			6-12-4	16.7	666
			4-8-4	14.4	480

was badly deficient 19% more of the total yield was obtained in the first picking where sufficient phosphorus was applied. Where the response to phosphorus was fair the addition of phosphorus without potash increased the amount of cotton in the first picking from 13 to 23%; with both nitrogen and potash applied, there was little difference in the earliness of cotton where 4, 8, and 12% phosphate was applied.

Potash made only small increases in the yield of cotton, and decreased earliness only slightly. The effect of potash was to offset about half of the increase in earliness produced by phosphorus. Without phosphorus, nitrogen had no influence on yield and earliness in one test, and increased the yield of seed cotton 374 pounds and the per cent of the total yield in the first picking by 13% in the other test. These data show that nitrogen increases earliness in cotton where it increases the yield.

Available phosphates are converted into less soluble and less available forms (39) when they are applied to the soil (Alabama):

No. of days phosphate applied before planting	Relative yields compared to monocalcium phosphate						
	No phosphate	Monocalcium phosphate	Dicalcium phosphate	Tricalcium phosphate	Superphosphate	Iron phosphate	Ammonium phosphate
0	2.1	100	104	57	117	25	110
30	...	71	78	59	94	33	97
180	...	69	33	38	88	21	53
365	...	8	13	10	8	20	13

The above data show that most phosphates become less available as the time after application before planting increases. In one year all of the good sources of phosphorus became less available than iron phosphate which is a poor source of phosphorus. The work of the Tennessee Experiment Station (18) suggests that the soluble phosphates are eventually converted into rock phosphate in limed soil. The fluorine present in superphosphate is sufficient to convert all of the phosphorus into rock phosphate. This conclusion suggests, but does not necessarily show, that fluorine should be removed from superphosphate or other sources of phosphorus before they are applied to the soil.

When superphosphate is broadcast for hay and grain crops, the phosphate comes in contact with a large quantity of soil. Under these conditions the phosphorus in regular superphosphate combines with the soil particles to a greater extent than does that in granulated superphosphate; consequently, granulated superphosphate produces larger yields. The following data were obtained in Sweden (10):

	Increase in yield of grain	
	Regular superphosphate	Granular superphosphate
	Pounds per acre	
400 pounds worked down into the soil with a plow..	360	415
400 pounds harrowed into the soil...............	95	135

Granular superphosphate was superior to regular superphosphate for broadcast application and for harrowing into the soil. The above data show that superphosphate which is to be applied broadcast should be applied before plowing or disking for crops, like lespedeza and other

broadcast crops. The phosphate which was plowed under probably came in contact with much less soil than did that which was harrowed into the soil.
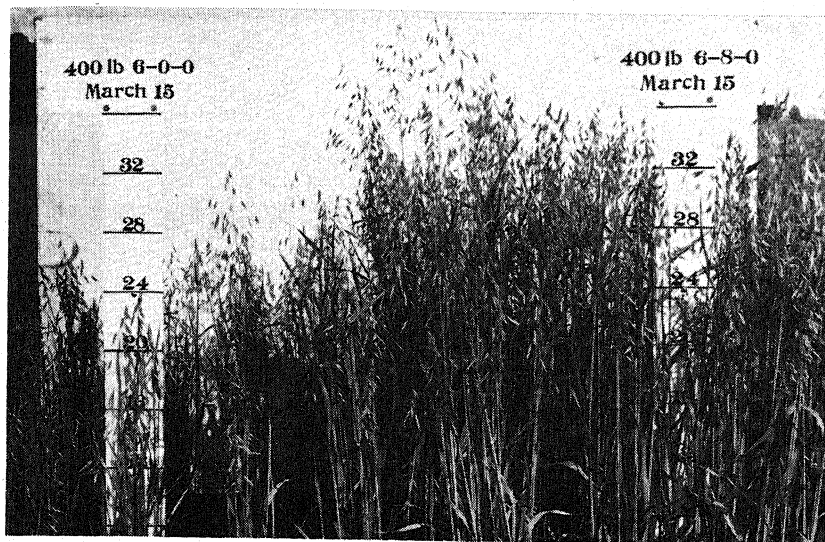
FIG. 8.—Some Mississippi soils are deficient in phosphorus for oats. (Courtesy Mississippi Agricultural Experiment Station.)

Granulated superphosphate may be distributed more uniformly than ordinary superphosphate. It does not accumulate on the distributing machinery as does ordinary superphosphate. Where granulated superphosphate is superior to ordinary superphosphate, its superiority is due to the phosphate in the granule coming in contact with less soil. The phosphate in granules is maintained in a water-soluble form longer than that in regular superphosphate.

Most of the experimental work which has been carried out in this country comparing granulated and ordinary fertilizers has been conducted in the Southeast with cotton. Complete fertilizers have been used. The fertilizers have been drilled so that even ordinary superphosphate comes in contact with very little soil, and an excess of superphosphate has probably been used. Consequently, the expected advantages of granulation have not been obtained with cotton fertilizers. The results may have been in favor of granulation if a known phosphate deficiency had existed, and the phosphate had been used at a rate which would have limited plant growth. It appears that granulated

superphosphate will probably have a greater chance to be superior to regular superphosphate for crops to which superphosphate is applied broadcast.

The effect of the lime content of the soil on the amount of superphosphate required for cotton production is shown by data collected in Mississippi (1). Where 24 pounds of nitrogen was used per acre on strongly acid soils, 48 pounds of phosphate was required for cotton production; on an alkaline soil, where phosphorus was extremely deficient, 12 pounds of phosphate was practically as good as more, where 24 pounds of nitrogen was used. It appears that the use of liberal quantities of lime will reduce the amount of superphosphate required to a fraction of that required on strongly acid soils.

Natural organic nitrogen costs from three to four times as much as nitrogen in sources like sulphate of ammonia, urea, ammonium nitrate, etc. Farmers often demand that mixed fertilizers contain some organic nitrogen. The demand is based upon experience with cottonseed meal and other organic fertilizers. The Alabama Agricultural Experiment Station has shown that the use of cottonseed meal as the source of nitrogen will overcome lime-induced boron deficiencies (24). If organic sources of nitrogen have a place from the standpoint of plant nutrients, it is due to the elements like magnesium, boron and other rare elements they contain. However, it is doubtful if organic sources of nitrogen have any value which can not be supplied by fertilizers containing no organic material.

When superphosphate is ammoniated with a standard solution containing ammonia, urea, and formaldehyde, and the temperature is correctly maintained, about 20% of the nitrogen is converted into a form which makes it water insoluble, and analysis shows it to be organic nitrogen just as nitrogen in cottonseed meal. One difference between this organic source of nitrogen and cottonseed meal is that it does not carry extra elements which cottonseed meal contains. Even though fertilizers may contain organic nitrogen made in the ammoniation process, no data are available upon its value for growing crops. As a source of nitrogen, it may be satisfactory, but it will not take the place of natural organic sources of nitrogen if they are needed for elements other than nitrogen. This nitrogen is probably much cheaper than nitrogen from natural organic sources.

Basic slag was inferior to lime and superphosphate for vetch production (4) in four out of six tests conducted in Mississippi (Table 6). Since very little response was obtained from the use of lime, the

Table 6.—The Response of Vetch to Superphosphate, Lime, and Basic Slag.

Test No.	1[1]	2[1]	3[1]	4[2]	5[2]	6[2]
Duration—Years	4	3	3	3	2	1
Treatment	Increase in yield of green vetch—lbs. per acre					
Superphosphate...	3,773	1,487	1,319	.....	.....	.....
Superphosphate and lime.......	4,185	2,236	1,763	4,223	3,494	3,272
Basic slag........	4,146	1,550	1,840	2,882	2,224	1,874
Lime...........	4	475	217	.....	.....	.....

[1] 43 pounds of phosphate, 400 pounds of dolomitic lime.
[2] 40 pounds of phosphate, 400 pounds of dolomitic lime.

superiority of the superphosphate and dolomite may have been due to a higher availability of the phosphorus in the superphosphate.

The value of basic slag as a source of phosphorus depends upon whether or not lime is more important than phosphorus, as well as on the crop grown. The Alabama Experiment Station conducted 222 tests (42) for short periods of time in which plant response to the fertilizers was obtained before the sulphate of ammonia with super- phosphate increased the acidity of the soils materially. The lime in the basic slag was more than sufficient to offset the acidity of the sulphate of ammonia. The fertilizers supplied 30 pounds of nitrogen, 64 pounds of phosphate, and 24 pounds of potash. The tests were con- ducted on eight soil groups. On two soil groups, basic slag and super- phosphate made almost equal yields; on one soil group, superphosphate made 145 pounds more seed cotton per acre than basic slag—an in- crease in value of $7.45 per acre for superphosphate over basic slag (Table 7). On the average, superphosphate made 62 pounds more seed cotton (value $3.10) than did basic slag, which indicates that super- phosphate is superior to basic slag as a source of phosphorus for cotton, even though a strongly acid source of nitrogen was used. Based on the

Table 7.—Yield of Cotton Fertilized with Ammonium Sulphate and Two Sources of Phosphorus—1927-1931.

Soil group No. tests	Clarkes- ville	De- catur	Houston	Hari- selle	Cecil	Oktib- beha	Green- ville	Nor- folk	General average
	10	32	21	36	17	15	34	57	222
Treatment[1]	Yield in pounds of seed cotton per acre								
400 Superphosphate..	932	804	999	1,036	892	791	936	891	914
600 Basic slag (10½%).........	787	739	970	926	800	796	872	855	852

[1]Both plots received 150 lbs. sulphate of ammonia and 50 lbs. muriate of potash.

response of cotton to dolomite in other tests, if dolomite had been used with superphosphate to offset the acidity of the sulphate of ammonia, there would probably have been over 100 pounds of seed cotton difference in favor of superphosphate.

Data obtained in Mississippi (unpublished) on sources of phos-
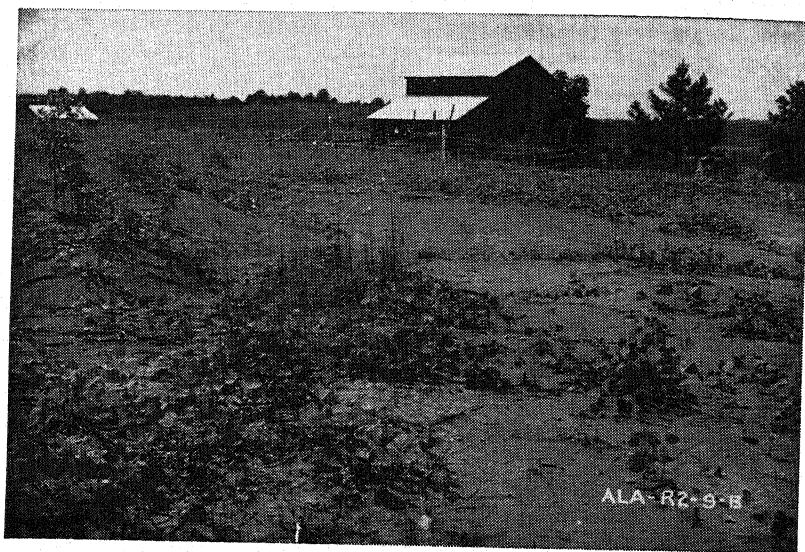
Fig. 9.—The application of 1600 pounds of basic slag per acre made the difference in the growth of kudzu. The basic slag was applied in 1939. The pictures were made in 1942. The kudzu produced 2¾ tons of hay per acre annually in 1940, 1941, and 1942 where fertilized (30). (Cut courtesy American Society of Agronomy.)

phorus indicate that the primary value of basic slag for cotton production (Table 8) may be due to its lime content (two years). Lime gave about the same increase in yield as basic slag. On limed soil, superphosphate made 89 pounds more seed cotton than did basic slag. The data reviewed indicate that the response of cotton to basic slag as a source of phosphorus is uncertain.

Table 8.—THE RESPONSE OF COTTON TO LIME AND TO SOURCES OF PHOSPHORUS.

Treatment—Source of phosphorus	Yield per acre	
	Unlimed soil	Limed soil
	Pounds	Pounds
600 lbs. 8-0-8......................	338	695
600 lbs. 8-5-8 (basic slag)............	729	766
600 lbs. 8-5-8 (superphosphate).......	440	855

Superphosphate is the primary source of phosphorus used as such by farmers. However, farmers use some triple superphosphate. The phosphorus in superphosphate and triple superphosphate is mostly monocalcium phosphate. Superphosphate and triple superphosphate are also the primary sources of phosphorus which go into mixed fertilizers; however, in the manufacturing process, ammonia and dolomite are added which convert much of the water-soluble monocalcium phosphate into less soluble dicalcium and tricalcium phosphates, and fluorphosphate.

Crops which have a short growing period require phosphate of higher solubility than do crops which grow throughout most of the year or for more than one year. Cotton has a long growing period, but its fruiting period is often short, due to boll weevils. Due to the short fruiting period under boll weevil conditions, cotton responds to phosphorus as if it were a short-season crop.

The response of cotton and vegetables crops to sources of phosphorus is probably quite similar. Since vegetable crops have a shorter growing period than cotton, phosphates of high solubility may be of more importance for them than for cotton. More field data on the comparative value of sources of phosphorus have been collected with cotton than with any other crop. Sources of phosphorus which are good for cotton will probably be good for other crops.

Superphosphate was the most efficient source of phosphorus for corn, wheat, tobacco, cotton, and peanuts in rotations in Virginia (27).

The average relative increase in yield for 8 tests for a total of 143 years was superphosphate 100, triple superphosphate 93, dicalcium phosphate 83, and tricalcium phosphate 71 (Table 9). Calcium meta-

Table 9.—The Response of Crops in Rotation to Sources of Phosphorus (Virginia).

Number of tests				Increase in yield per acre						Weighted relative increase
Number of tests	Corn 6	Wheat 6	To-bacco 3	Red clover 3	Al-falfa 2	Cot-ton 1	Pea-nuts 1	Pota-toes 1	8
Total number of years	40	40	20	8	15	7	6	7	143
Source of phosphorus	Bus.	Bus.	Lbs.	Tons	Tons	Lbs.	Lbs.	Bus.	
Commercial superphosphate...	6.2	3.9	263	0.17	0.59	322	201	30	100
Dicalcium phosphate.........	5.6	3.2	208	0.17	0.57	192	34	34	83
Triple superphosphate........	6.2	3.6	214	0.19	0.66	294	92	39	93
Calcium metaphosphate.......	7.1	3.7	248	0.30	0.47	276	233	23	93
Tricalcium phosphate	4.8	2.5	170	0.14	0.54	225	113	21	71
Fused rock phosphate.........	4.1	3.1	218	0.19	....	52	8	..	..
Raw rock phosphate..........	2.9	1.4	188	0.16	0.37	152	116	14	32
Triple superphosphate and gypsum.................	6.6	4.3	320	0.31	0.69	342	233	30	112
Triple superphosphate and dolomite................	5.0	4.3	292	0.30	0.48	414	298	27	110
Triple superphosphate and ground calcium silicate slag .	4.9	4.4	252	0.22	0.57	231	173	33	102
Triple superphosphate and granular calcium silicate slag .	4.2	4.1	290	0.28	0.47	255	127	33	105
Yield without phosphate......	48.4	15.4	792	0.94	1.94	911	1,517	61	...

phosphate was a good source of phosphorus, while fused rock phosphate and raw rock phosphate were poor sources. The calcium silicate slags were less desirable than dolomite for neutralizing acid-forming fertilizers.

The data on sources of phosphorus reported in Table 10 were ob-

FIG. 10.—Tobacco needs quickly available phosphorus. Left, rock phosphate; right, triple super-phosphate (27). (Courtesy Virginia Agricultural Experiment Station.)

Table 10.—The Response of Cotton to Sources of Phosphorus.

Source of phosphorus	Alabama		Miss.	Georgia		
	Acid fertilizer			Acid fertilizer	Neutral fertilizer	
	358[1] tests	185[1] tests	38[2] tests	9[3] tests	9[3] tests	4[1] tests
	Increase in yield of seed cotton—lbs. per acre					
Superphosphate.............	246	241	131	142	124	121
Monocalcium phosphate[4]......	227	...	124	150	121	...
Dicalcium phosphate.........	244	...	126	154	112	...
Tricalcium phosphate.........	200	206	98	92	68	12

[1] 600 pounds of 6-10-4 fertilizer per acre.
[2] 400 pounds of 4-8-4 fertilizer per acre.
[3] 500 pounds of 6-6-6 fertilizer per acre.
[4] Including triple superphosphate.

tained throughout the Southeast (3, 7, 49, 50). The source of nitrogen was sulphate of ammonia in all except the Mississippi tests, where 10% of the nitrogen was derived from cottonseed meal and 90% from sulphate of ammonia. Superphosphate usually produced as much increase in yield of seed cotton as any other source of phosphorus. Monocalcium phosphate, which is essentially the same as triple superphosphate, produced 19 pounds less seed cotton than did superphosphate in the 358 experiments in Alabama. The superiority of regular superphosphate to monocalcium phosphate may have been due to the calcium supplied by the calcium sulphate it contained.

Tricalcium phosphate produced considerably less seed cotton than superphosphate. On the basis of one ton of mixed fertilizer, when
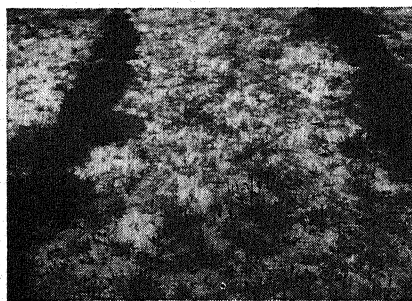
Fig. 11.—The response of broadcast lespedeza to phosphorus applied to row crops three years previously. (Courtesy Mississippi Agricultural Extension Service.)

tricalcium phosphate was used as the source of phosphorus instead of superphosphate, the following differences in value were obtained:

In Alabama (385 tests) $7.67 was lost.
In Alabama (185 tests) $5.83 was lost.
In Mississippi (38 tests) $8.25 was lost.
In Georgia (acid fertilizers) (9 tests) $10.00 was lost.
In Georgia (neutral fertilizers) (9 tests) $11.20 was lost.
In Georgia (neutral fertilizers) (4 tests) $18.50 was lost.

The above tests were conducted throughout the Southeast on soils which are predominantly acid, and sulphate of ammonia was used as the source of nitrogen. These fertilizers were acid forming (except for 9 tests in Georgia), and in acid fertilizers tricalcium phosphate gives better results than in neutral fertilizers which are so generally used. The data were less favorable to tricalcium phosphate where neutral fertilizers were used. In neutral fertilizers in four tests in Georgia, tricalcium phosphate made $18.50 less profit per ton of 6-10-4 fertilizer than did superphosphate.

   The response of cotton to sources of phosphorus on an alkaline soil is shown by the following data (2) from Mississippi:

Source of phosphorus	Increase in yield—lbs. seed cotton per acre
Triple superphosphate....................	227
Dicalcium phosphate.....................	185
Tricalcium phosphate....................	73

Sulphate of ammonia was used as the source of nitrogen. On the alkaline soil dicalcium phosphate produced 42 pounds less and tricalcium phosphate produced 154 pounds of seed cotton less than did triple superphosphate. Evidently dicalcium and tricalcium phosphates are poor sources of phosphorus on alkaline soils. These data suggest that dicalcium and tricalcium phosphates will be less valuable in neutral than in acid fertilizers, which is partially borne out by the Georgia data (above).

   The effect of source of nitrogen upon the response of Sudan grass (in pots containing sand) to tricalcium phosphate is shown by the following data of Truog (34):

Source of nitrogen	Source of phosphorus	Yield— grams per pot
Potassium nitrate and calcium nitrate....	Tricalcium phosphate...	4.34
Sulphate of ammonia and calcium nitrate..	Tricalcium phosphate...	47.52
Potassium nitrate and calcium nitrate....	Monocalcium phosphate.	38.00

With sulphate of ammonia used as part of the nitrogen in the sand cultures, the nitric and sulphuric acids formed from it brought sufficient phosphorus into solution from tricalcium phosphate for plant growth. With potassium nitrate and calcium nitrate as the source of nitrogen, tricalcium phosphate had no value as a source of phosphorus. These two sources of nitrogen reduce the acidity when nitrogen is used by plants.

The failure of tricalcium phosphate to become as available as more soluble sources of phosphorus for cotton production in the field with sulphate of ammonia as the source of nitrogen above suggests that the acid-forming sulphate of ammonia diffused out of the fertilizer zone before it was converted into nitric and sulphuric acids.

Dicalcium phosphate has been a good source of phosphorus for cotton in acid fertilizers on acid soils, but it was inferior to triple superphosphate on an alkaline soil in Mississippi; it was slightly inferior in neutral fertilizers in Georgia; and in Rhode Island it was very much inferior to superphosphate for oats and millet in pot tests on limed soils.

The response of corn, wheat, and hay to sources of phosphorus in Kentucky (32) is shown by the data in Table 11. Corn received 6 pounds of phosphate per acre in the hill, and wheat received 40 pounds of phosphate broadcast. The hay crops followed wheat and received no direct application of phosphate. Ordinary superphosphate, triple superphosphate, dicalcium phosphate, and calcium metaphosphate were apparently equally satisfactory for corn, wheat, and hay.

Tricalcium phosphate was almost as good as any source of phosphorus for hay on both limed and unlimed soil, and for wheat on the unlimed soil. It produced considerably less corn on both limed and unlimed soil, and less wheat on the lime soil. Tricalcium phosphate was satisfactory for hay, but not satisfactory for other crops. The unusually good, though somewhat unsatisfactory, results which were obtained with tricalcium phosphate were probably due to the fact that most of the phosphorus was applied broadcast. When phosphates are mixed with the soil tricalcium phosphate compares more favorably with other sources of phosphate than when they are drilled.

Fused rock phosphate made a good showing in the two tests in which it was used, which may also be due to broadcast application.

Rock phosphate usually gives unsatisfactory results. However, in the above two tests, it produced good increases in the yield of hay on unlimed soil. Rock phosphate produced slightly more than half as much wheat and corn on unlimed soil as the other sources. Rock phosphate produced very low increases in yield on limed soil. The data on rock phosphate show that it is generally inferior to superphosphate; however, the best use for it appears to be on broadcast hay crops.

Table 11.—THE RESPONSE OF CORN, WHEAT, AND HAY TO SOURCES OF PHOSPHORUS

Number of locations, and sources of phosphorus	Unlimed			Limed		
	Corn 61 crops	Wheat 51 crops	Hay 38 crops	Corn 61 crops	Wheat 51 crops	Hay 38 crops
Eleven locations, 1934-1939	Bus.	Bus.	Lbs.	Bus.	Bus.	Lbs.
No phosphate checks, acre yields.	22.3	7.4	2,028	27.4	9.2	2,939
Acre increases produced by:						
Ordinary superphosphate.....	8.3	9.4	785	8.8	10.4	1,114
Triple superphosphate.......	8.1	9.3	731	8.9	10.6	1,119
Dicalcium phosphate........	7.8	10.1	701	7.7	10.9	1,099
Tricalcium phosphate........	6.9	9.0	773	5.8	7.7	1,033
	Corn 8 crops	Wheat 6 crops	Hay 6 crops	Corn 8 crops	Wheat 6 crops	Hay 6 crops
Two locations, 1936-1939	Bus.	Bus.	Lbs.	Bus.	Bus.	Lbs.
No phosphate checks, acre yields.	20.9	3.8	2,012	23.1	4.0	2,758
Acre increases produced by:						
Triple superphosphate.......	10.0	9.0	1,009	13.8	9.3	1,663
Calcium metaphosphate......	12.7	9.3	1,202	12.6	10.6	1,671
Fused rock phosphate.......	9.7	10.9	1,306	10.2	11.2	1,795
Raw rock phosphate (ground).	6.6	5.8	1,007	3.3	1.9	837

The use of lime in one of the above tests increased the yield of crops as follows: corn 5 bushels, wheat 2 bushels, and hay 900 pounds per acre; the increases were smaller in the other test. The increase in yield of corn and wheat due to phosphorus was slightly higher on limed soil. Phosphorus usually increased the yield of hay crops 50% more on limed soil than on unlimed soil. These data show that lime increased the efficiency of superphosphate.

The response of cotton to ammoniated superphosphate is shown by data (50) in Table 12. In acid fertilizers 2.4% ammonia ammoniated

superphosphate was equal to superphosphate, and 5.4% ammonia ammoniated superphosphate was inferior to superphosphate. When dolomite was used, superphosphate made 60 pounds of seed cotton per acre more than 5.4% ammonia ammoniated superphosphate. On the basis of a ton of mixed fertilizer, superphosphate produced $10.00 more seed cotton than 5.4% ammonia ammoniated superphosphate.

The 6-10-4 analysis fertilizer used in the tests contained more phosphorus relative to the other two elements than is usually recommended for cotton production. The data therefore may show a higher availability for ammoniated superphosphates than would have been obtained if less phosphate had been used.

Table 12.—Average Increase in Yield of Seed Cotton on Various Soil Regions from Different Sources of Phosphate.

Plot No.	Source of phosphate kind of supplement[1]	Clarkes-ville soils 29 tests	De-catur soils 33 tests	Hart-selle soils 28 tests	Cecil soils 27 tests	Green-ville soils 19 tests	Nor-folk soils 49 tests	Average 185 tests
		Increase in pounds seed cotton per acre						
2	Superphosphate................	308	214	298	262	96	231	241
3	2.4% ammoniated superphosphate (1.92% N)[2]..................	303	234	291	268	102	225	242
4	5.4% ammoniated superphosphate (4.4% N)[3]..................	262	198	271	248	100	205	218
5	Precipitated tricalcium phosphate...	263	191	280	259	47	170	206
7	Superphosphate and ground lime-stone[4]......................	375	265	381	358	84	261	294
8	5.4% ammoniated superphosphate (4.4% N)[3] and ground limestone[4]..	303	183	326	287	68	212	234

[1]Fertilizer 600 lb. per acre of 6-10-4. Nitrogen from ammonium sulphate sufficient to make 6% N; phosphoric acid from source indicated; potash from muriate of potash.
[2]Actual analysis 1931, 1.53% N; 1932, 2.10% N; 1933, 2.06% N; 1934, 2.00% N. Average 1.92% N.
[3]Actual analysis was 5.40% N, 1931; 4.65% N on Norfolk, Greenville, and Cecil groups and 3.64% N on Hartselle, Decatur, and Clarkesville groups in 1932; 4.01% N, 1933; 4.00% N, 1934. Average 4.40% N.
[4]Marble dust, 200 lbs. per acre, in 1931; 200 lbs. dolomite per acre in 1932, 1933, and 1934.

The Georgia Agricultural Experiment Station[1] **compared super-phosphate with tricalcium phosphate and ammoniated superphosphate containing different percentages of ammonia.** There were four tests which were conducted for three years. The fertilizers used were 600 pounds of 6-0-4 or 6-10-4 per acre. The source of nitrogen, other than that in the ammoniated superphosphate was sulphate of ammonia. The neutral fertilizers contained 250 pounds of limestone per acre. The data are reported in Table 13. The data (7) show that ammoniated super-phosphate containing as high as 5% ammonia was satisfactory for cotton production in acid fertilizers, and that tricalcium phosphate was inferior to superphosphate in acid fertilizers.

In neutral fertilizers superphosphate ammoniated with 1.86% am-

[1]Unpublished data supplied by R. P. Bledsoe.

monia was as effective as superphosphate. Superphosphate ammoniated with 3.00%, 3.67%, or 5.01% ammonia was considerably inferior to superphosphate. The decrease in income as compared to superphosphate was $12.83, $14.33, and $8.00 per ton of fertilizer for 3.00%, 3.67%, and 5.01% ammonia ammoniated superphosphate in neutral fertilizers, respectively.

In the neutral fertilizer where superphosphate was ammoniated with 3% ammonia, 3.1 pounds more nitrogen per acre came from ammonia than where it was ammoniated with 1.86% ammonia; the yield of seed cotton was reduced 88 pounds per acre. If the additional 3.1 pounds of ammonia nitrogen had been omitted, the yield of cotton might not have been reduced more than about one-third as much as it was

Table 13.—The Response of Cotton to Ammoniated Superphosphates.

Source of phosphorus in 600 pounds of 6-10-4 fertilizer	Increase in yield of seed cotton per acre		Value of increase in neutral fertilizer per acre	Value of increase in neutral fertilizer as compared to superphosphate	
	Acid fertilizer	Neutral fertilizer		Per acre	Per ton of fertilizer
	Pounds	Pounds	Dollars	Dollars	Dollars
Superphosphate..................	163	121	6.05	....	.....
1.86% ammoniated superphosphate	158	132	6.60	0.55	1.83
3.00% ammoniated superphosphate	146	44	2.20	−3.85	−12.83
3.67% ammoniated superphosphate	149	35	1.75	−4.30	−14.33
5.01% ammoniated superphosphate	149	73	3.65	−2.40	− 8.00
Tricalcium phosphate...........	140	12	0.60	−5.55	−18.50

reduced by the extra ammonia decreasing the value of the phosphate. The additional 3.1 pounds of nitrogen would increase the yield about 30 pounds of seed cotton. Where 3.67% ammonia ammoniated superphosphate was used, 5 pounds more nitrogen came from ammonia than where it was ammoniated with 1.86% ammonia; the yield of seed cotton was reduced 97 pounds per acre, which is probably twice as much as omitting 5 pounds of nitrogen would have reduced the yield. It appears that the use of more than 1.86% ammonia in superphosphate reduced the value of the phosphate by an amount equal to two to three times the increase in yield obtained from the nitrogen—in other words the ammonia added in excess of 1.86% of the superphosphate decreased the yield due to a decrease in the value of the phosphate. Ammoniating superphosphate with 5.01% ammonia reduced its value, but not to the same extent as where 3.0% and 3.67% am-

monia were used, which is attributed to experimental error. On the basis of the data superphosphate ammoniated with 1.86% ammonia was as effective as superphosphate, and the 3.0%, 3.67%, and 5.01% ammonia ammoniated superphosphate were less valuable.

When tricalcium phosphate was used as the source of phosphorus in neutral fertilizers, $18.50 less cotton per ton of fertilizer was produced than with superphosphate.

Due to the high amount of phosphorus used relative to the nitrogen and potash, the ammoniated superphosphates and tricalcium phosphate may have produced higher relative yields than would be anticipated where less phosphorus is present in the fertilizer.

The efficiency rating of sources of phosphorus for the production of wheat (grain) is shown by the data from Ohio (38) in Table 14.

Table 14.—THE RESPONSE OF WHEAT (GRAIN) TO SOURCES OF PHOSPHORUS.

Source of phosphorus	pH of soil			
	5.5	6.0	7.0	Average
	Relative increase in yield			
Superphosphate 20%...............	100	100	100	100
Monocalcium phosphate.............	86	81	120	98
Dicalcium phosphate................	49	64	90	70
Tricalcium phosphate...............	57	38	23	38
Ammonium phosphate...............	69	73	112	87
Ammoniated superphosphate 2.5% N[1]..	94	74	100	90
Ammoniated superphosphate 5.0% N[1]..	72	48	59	59
Rock phosphate....................	6	3	6	5

[1]N =nitrogen as ammonia.

Monocalcium phosphate and superphosphate were about equal for wheat production. Dicalcium phosphate and particularly tricalcium phosphate were poor sources of phosphorus. Rock phosphate had little value for wheat production. Ammoniating superphosphate with 2.5% nitrogen decreased its value to 90% of that of superphosphate, and superphosphate ammoniated with 5% nitrogen was only 59% as effective as superphosphate.

The availability of superphosphate, ammoniated superphosphate, dicalcium phosphate, tricalcium phosphates, and rock phosphate was determined in carefully controlled pot tests on limed soil in Rhode Island (11) (Table 15). On the basis of the Rhode Island data, where the response of crops to fertilizers is dependent upon the quality of the phosphate, and the increase in yield of crops due to fertilizer is three times the cost of the fertilizer, the use of approximately 2.5%

Table 15.—The Response of Oats and Millet to Ammoniated Superphosphates.

Source of phosphorus	Relative increase in yield	
	Oats	Millet
Superphosphate....................................	100	100
Ammoniated superphosphate 2.48% ammonia..........	85	93
Ammoniated superphosphate 2.69% ammonia..........	87	85
Ammoniated superphosphate 3.52% ammonia..........	96	80
Ammoniated superphosphate 4.71% ammonia..........	81	83
Dicalcium phosphate...............................	78	67
Ammoniated superphosphate 6.53% ammonia..........	69	64
Ammoniated superphosphate 6.83% ammonia..........	63	54
Tricalcium phosphate..............................	45	49
Tricalcium phosphate..............................	44	55
Tricalcium phosphate..............................	44	54
Rock phosphate...................................	6	1

ammonia in superphosphate reduced the income equal to half of the cost of the fertilizer. Likewise, the use of highly ammoniated super-phosphate reduced the income more than the cost of the fertilizer. The use of dicalcium phosphate reduced the income nearly as much as the cost of the fertilizer, and tricalcium phosphate reduced the income more than twice the cost of the fertilizer. Rock phosphate had little value in these tests.

The validity of the present official method for determining available phosphorus in mixed fertilizers was tested in experiments reported by Ross, et al. (33). There were nine pot tests conducted by the U.S.D.A. and cooperating state experiment stations. The data are reported in Table 16. The data show that relative increases in plant

Table 16.—The Availability of Phosphorus as Measured by Plant Response and Chemical Methods

No. of Sample	Rate of ammoniation	Availability found by chemical methods		Availability found by plants	
		1-gram sample[1] present method	2-gram sample[1] old method	All crops	Short season crops
	Percent	Percent	Percent	Percent	Percent
1 S-1......	0	95	93	100	95
2 S-2......	2	94	91	100	93
3 S-3......	3	94	87	88	80
4 S-4......	4	94	85	82	72
5 S-5......	5	93	80	65	50

[1]As determined on a 4-12-4 base mixture.

growth of 100, 100, 88, 82, and 65% were produced with 0, 2, 3, 4, and 5% ammonia in the superphosphate, and that the relative availability with the present official method for determining available phosphorus was 95, 94, 94, 94, 93% respectively. The response of plants varied from 100 to 65%, while the official method varied only from 95 down to 93%. The variation by the chemical method is probably within the allowable error of control chemists.

On the basis of the above data, the present chemical method would indicate a 2% loss in available phosphorus where the plant data show a 35% loss.

The chemical data obtained with the 2-gram sample are in much closer agreement with plant response than are those obtained with the 1-gram sample. With a 2-gram sample the relative chemical availability was 93, 91, 87, 85, 80; and, the relative plant response was 100, 100, 88, 82, and 65 for 0, 2, 3, 4, and 5% ammonia in the superphosphate, respectively. Even the 2-gram sample shows a much higher availability for highly ammoniated superphosphates than was shown by plants. The chemical data were obtained on a 12% phosphate fertilizer. Most fertilizers used in the Southeast contain less than 12% phosphate, and the present method of chemical analysis permits these fertilizers to contain a still higher percentage of the phosphorus in the less available forms. As has been pointed out either the size of the sample or the volume of ammonium citrate solution could be varied so that a constant ratio is maintained between total phosphate and the volume of ammonium citrate solution where fertilizers contain different percentages of phosphorus.

The data presented (33) show the use of a 2-gram sample in the official ammonium citrate method more accurately evaluates phosphate availability than the procedure of using a 1-gram sample. The relative availability of the phosphate in non-ammoniated and 2% ammoniated superphosphates with a 1-gram sample was 95 and 94, and with a 2-gram sample 93 and 91, respectively. For these superphosphates the 1-gram sample appears to be more desirable than the 2-gram sample; however, the difference in the results obtained with a 1-gram and with a 2-gram sample are so small that they are within the allowable error of control chemists. The data, therefore, suggest that either the 1-gram or the 2-gram sample may be equally satisfactory for determining the chemical availability of non-ammoniated and 2% ammoniated superphosphate-containing fertilizers.

The use of a 1-gram sample appears to be satisfactory for determining available phosphorus in 12% phosphate fertilizers containing

non-ammoniated and 2% ammoniated superphosphates; however the data show that the 1-gram sample is unsatisfactory if fertilizers contain 3% or higher ammoniated superphosphates. Therefore, the suitability of the present method for determining available phosphorus is dependent upon the degree to which superphosphates are ammoniated by fertilizer manufacturers. The above data show that the present method for determining available phosphorus permits an unsatisfactory rate of ammoniation of superphosphate.

Data on the percentage of ammonia used in the ammoniation of superphosphate by fertilizer mixers are not generally available. However, calculated on the basis of 20% superphosphate, Parker and Ross (28) made the recommendations below for the 1943-44 fertilizer year. They stated that: "In collaboration with the technical men of the major producers we have prepared the following general recommendations on the use of ammonia solutions. These recommendations represent standard rates of ammoniation under average conditions. Many operators use substantially higher rates, especially where there are facilities for reducing storage temperatures or where the storage period is relatively short."

Initial storage temperature	*Percent phosphate in the fertilizer*	
	8%	*12%*
	Recommended percent of ammonia on basis of 20% superphosphate	
Below 110° F..................	3.75	3.00
110° F. to 125° F...............	3.13	2.50
Above 125° F..................	2.50	2.08

Ross et al. (33) presented data which show that the present chemical method for determining available phosphorus is not satisfactory if the superphosphates are ammoniated to 3% or more ammonia; and Parker and Ross (28) recommended 3.75% ammonia. The higher rates of ammonia recommended for the 8% phosphate fertilizer appear to take into consideration the fact that the present method for determining available phosphorus will determine a higher percentage of less available phosphates as available in an 8% phosphate fertilizer than in a 12% phosphate fertilizer.

In so far as the recommendations of Parker and Ross (above) are

followed in the fertilizer industry, the phosphate in high phosphate fertilizers is more available to plants than that in low phosphate containing fertilizers.

The pot test data presented above may be used to establish an equitable chemical method for determining available phosphorus. The relative plant response to the different superphosphates was — 157.6 + 2.805 times relative chemical solubility with a 2-gram sample of 12% phosphate fertilizer. Using the above relationship, plant response was calculated from chemical solubility and recorded by the actual plant response in Table 17. The calculated plant responses are almost

Table 17.—A COMPARISON OF PLANT RESPONSE TO AMMONIATED SUPERPHOSPHATES WITH PLANT RESPONSES CALCULATED ON THE BASIS OF CHEMICAL SOLUBILITIES OF A 2-GRAM SAMPLE OF 12% PHOSPHATE FERTILIZER.

No. of sample	Rate of ammoniation	Relative chemical solubility 2-gram sample	Relative availability to plants	
			Found	Calculated
	Percent	Percent	Percent	Percent
1—S 1..............	None	93	100	103
2—2 2..............	2	91	100	98
3—S 3..............	3	87	88	86
4—S 4..............	4	85	82	81
5—S 5..............	5	80	65	67

identical to the plant responses in the test. If the weight of the sample taken for analysis or if the volume of ammonium citrate solution were varied so that the ratio of solution to phosphate remained the same as where a 2-gram sample of 12% phosphate fertilizer (above) was used, the calculated data would apparently be in harmony with plant response to the different superphosphates.

The effect of dolomite and ammoniation of superphosphate on the availability of phosphorus to cotton is shown by the data[1] reported in Table 18. The treatments were 6-0-6, with phosphorus from the indicated sources. The final mixed fertilizers were all made neutral with dolomite according to the official method.

The time lapsed after the dolomite was mixed with the superphosphate apparently influenced the efficiency of the phosphate. Superphosphate No. 2 was treated with 250 pounds of dolomite; superphosphate No. 1 was not treated with dolomite. The mixed fertilizers in

[1]Unpublished, Mississippi Agricultural Experiment Station. The superphosphates were prepared under the supervision of Dr. W. H. Ross of the Bureau of Plant Industry.

which both superphosphates were used were made neutral with dolomite according to the official method. With superphosphate No. 2 part of the dolomite was mixed several weeks before application; in the case of superphosphate No. 1, the dolomite was put into the mixture only a few days before application.

Table 18.—THE EFFECT OF TREATING SUPERPHOSPHATE WITH AMMONIA AND DOLOMITE ON THE AVAILABILITY OF THE PHOSPHORUS TO COTTON.

Test No.	*1*	*2*	*3*	*4*	*5*		*Average both rates*
Pounds fertilizer per acre	*600*	*800*	*800*	*600*	*600*	*Average*	
Superphosphate No. and treatment	*Increase in yield—lbs. seed cotton per acre*						
	High phosphorus rate						
1. No treatment...............	1,131	611	285	368	140	507	436
2. Based per ton with 250# dolomite................	975	476	182	256	65	391	326
3. 4.73% ammonia, cooled quickly..................	580	405	180	250	114	306	248
4. 4.71% ammonia maintained at 60°C. for 30 days.......	637	336	183	212	127	299	233
5. 4.90% ammonia, 250# dolomite per ton cooled quickly.	673	391	168	290	113	327	262
6. 4.78% ammonia, 250# dolomite maintained at 60°C. for 30 days..............	555	469	112	158	128	284	225
	Low phosphorus rate						
1. No treatment...............	744	522	202	231	133	366	
2. 250# dolomite per ton......	494	384	143	233	51	261	
3. 4.73% ammonia, cooled quickly..................	263	391	100	156	44	191	
4. 4.71% ammonia, maintained at 60°C. for 30 days.......	219	370	101	115	29	167	
5. 4.90% ammonia, 250# dolomite per ton, cooled quickly.	376	336	42	137	93	197	
6. 4.78% ammonia, 250# dolomite per ton maintained at 60°C. for 30 days.........	260	330	109	69	65	167	

Mixing the dolomite with the superphosphate well in advance of application reduced the average yield of seed cotton 116 pounds per acre at the high phosphate rate and 105 pounds per acre at the low phosphate rate as compared to mixing them a few days in advance of application. The value of 116 and 105 pounds of seed cotton at 5 cents per pound is $5.80 and $5.25, respectively.

The average increase in yield for superphosphate No. 1 was 507

and 366 pounds of seed cotton per acre at the high and low rate, respectively. Superphosphate No. 2 increased the yield 391 pounds of seed cotton at the high rate. It is, therefore, apparent that mixing dolomite with superphosphate well in advance of application reduced its value to slightly more than half the value where they were mixed only a few days in advance of application.

Dolomite mixed with complete fertilizers by experiment station workers, presumably a few days in advance of application, has increased the yield of crops in hundreds of tests. The above data suggest that the data collected by experiment stations on neutralizing acid-forming fertilizers with dolomite may not be applicable to factory mixed fertilizers, and that factory mixed fertilizers should not be made neutral with dolomite, which would necessitate the use of acid-forming fertilizers and lime, separately, rather than neutral fertilizers.

The dolomite used (250 pounds per ton of superphosphate) was sufficient to convert the monocalcium phosphate into dicalcium phosphate under equilibrium conditions. Since the mixture of dolomite and superphosphate could not possibly be homogeneous, the conversion of a considerable part of the phosphate to tricalcium phosphate, which would in turn be converted into fluorphosphate, might be anticipated. The low availability of phosphate in the two last named forms is recognized.

The availability of the phosphorus in dicalcium phosphate is open to question. In many tests it has been a poor second to more soluble sources of phosphorus; and in many other tests, too much phosphate has been used to determine differences in efficiency of the different sources.

The ammoniated superphosphates increased the average yield of seed cotton 306, 299, 327, and 284 pounds per acre at the high phosphate rate as compared to 507 pounds for the untreated superphosphate at the high rate and 366 pounds at the low rate (Table 18). In only one out of the five tests was the increase in yield produced by the untreated superphosphate at the half rate exceeded by any of the ammoniated superphosphates at the full rate. **These data suggest that the efficiency of the ammoniated superphosphates for cotton production was less than one-half that of untreated superphosphate.**

The ammoniated superphosphates received slightly less than the amount of ammonia required to convert the phosphates into dicalcium phosphate under equilibrium conditions. It is doubtful that the ammoniation of superphosphate is so controlled that the formation of dicalcium phosphate primarily would result; of greater probability

would be the formation of a considerable amount of the still less available tricalcium phosphate and fluorphosphate.

The data presented in Table 19 on the response of Sudan grass to

Table 19.—The Response of Sudan Grass to Ammoniated Superphosphates.

No.	Superphosphate treatment			Pounds of phosphate per acre		
	Dolomite	Percent ammonia	Storage temperature	None	40	80
				Yield—lbs. green Sudan grass per plot		
None	....	....	....	80.3	....	....
1	none	none	....	....	91.8	95.2
3	none	4.73	20° C.	....	89.2	90.3
4	none	4.71	60° C.	....	89.8	94.4
5	present[1]	4.90	20° C.	....	90.5	91.3
6	present[1]	4.78	60° C.	....	87.9	88.7

[1] 250 pounds of dolomite was used per ton of 20% superphosphate.

ammoniated superphosphates substantiate the low availability of the phosphorus in ammoniated superphosphates (46) found with cotton as reported above. The superphosphates were the same as those used in the cotton tests. The ammoniated superphosphates produced less Sudan grass at both phosphates rates than did unammoniated superphosphate. The average yield of Sudan grass for the ammoniated superphosphates at the high phosphate rate was slightly less than that for the unammoniated superphosphate at the low phosphate rate.

The effect of ammoniation of superphosphate on the availability of phosphorus to cotton is suggested by data collected in North Carolina (40) in tests designed to study the effect of soluble fertilizer salts on the yield of cotton. The data discussed are those for side placement of the fertilizers, where salt concentration did not affect the yield. With the 9-12-12 fertilizer the average yield for two rates was:

	Yield—lbs. of seed cotton per acre
Low salt index 9-12-12 fertilizer...................	1,783
High salt index 9-12-12 fertilizer................	1,747

The high salt index of the 9-12-12 fertilizer had little if any effect on the yield of cotton, which suggests that differences in the salt index of the 6-8-8 fertilizers had no effect on the yield of cotton where a desirable fertilizer placement was used. If this interpretation is correct, the dif-

ference in the yield of cotton with the two 6-8-8 fertilizers was probably due to ammoniation of the superphosphate. The average yields for two rates are as follows:

	Yield—lbs. of seed cotton per acre
High salt index 6-8-8 fertilizer—no ammoniation...	1,858
Low salt index 6-8-8 fertilizer—superphosphate ammoniated to 4½% ammonia.................	1,619

The data suggest that the ammoniation of the superphosphate reduced the yield 239 pounds of seed cotton per acre, or 869 pounds per ton of fertilizer valued (5 cents per pound of seed cotton) at $43.45 per ton of 6-8-8 fertilizer. On one year ammoniation apparently reduced the yield of seed cotton 277 pounds per acre at the 400 pound rate and 495 pounds per acre where 700 pounds of fertilizer was used. One of the 9-12-12 fertilizers was also ammoniated; however, in the case of the 9-12-12 fertilizer, the sources of phosphorus were such that most of the phosphorus was probably water-soluble after ammoniation. In the case of the 6-8-8 fertilizer, much of the phosphorus was probably reverted to unavailable forms by ammoniation. These data are in agreement with the field data on cotton and Sudan grass, and with the greenhouse data with different crops above where ammoniated superphosphates were tested.

Synthetic and by-product ammonia have been used to a considerable extent in the ammoniation of superphosphate. Data were reviewed above which show that an average of 4.78% ammonia in superphosphate reduced the average yield of seed cotton 5 pounds per pound of phosphate in a 6-6-6 fertilizer as compared to unammoniated superphosphate. This is a reduction in yield of 800 pounds of seed cotton, per ton of 8% phosphate fertilizer. The value of 800 pounds of seed cotton at 5 cents per pound is $40, which is a loss to the farmer.

Only 31 pounds of nitrogen is supplied by ammonia when the superphosphate (20%) in a ton of 8% phosphate fertilizer is ammoniated with 4.78% ammonia. If nitrogen as ammonia is 4 cents per pound cheaper than other sources, only $1.24 is saved by the mixer, as compared to the farmer's $40 loss. It appears that the use of ammonia in ammoniating superphosphate should be limited to a rate which is barely sufficient to neutralize the free phosphoric acid in the superphosphate.

Ammonia used in the ammoniation of superphosphate is normally obtained from a solution of ammonia in water, or from solutions containing urea, or ammonium nitrate, or ammonium nitrate and

nitrate of soda. The ammonia which changes water soluble phosphate to water insoluble phosphate is the free ammonia in the solution. Ammonia in ammonium nitrate does not change water soluble phosphate to water insoluble phosphate.

The efficiency of the phosphorus in mixed fertilizers occurring on the market was tested by the Mississippi Agricultural Experiment Station. The data (unpublished) are reported in Table 20. The ferti-

Table 20.—THE EFFICIENCY OF THE PHOSPHORUS IN MIXED FERTILIZERS.

Fertilizer No.	Pounds seed cotton per acre	
	Yield	Increase
1	1,574	471
2	1,740	637
3	1,779	676
4	1,633	530
5	1,618	517
6	1,686	583
7	1,744	641
8	1,699	596
9	1,696	593
10	1,896	793
11	1,753	650
12	1,758	655
13	1,615	512
Superphosphate	1,720	617
½ superphosphate rate	1,555	552
No phosphorus	1,103	...

lizers were made up to a 6-6-6 ratio for test purposes with ammonium nitrate, muriate of potash, and dolomite and applied at the rate of 600 pounds of neutral fertilizer per acre.

Three out of the 13 fertilizers made at least 100 pounds of seed cotton per acre less than where superphosphate was the source of phosphorus; these fertilizers made less than where only one half of the normal rate of phosphorus was used as superphosphate. Only one fertilizer made 100 pounds of seed cotton per acre more than where superphosphate was the source of phosphorus. The reason for the superiority of this fertilizer was not determined.

THE OFFICIAL METHOD FOR DETERMINING AVAILABLE PHOSPHORUS IN FERTILIZERS

The principal phosphatic materials used for fertilizers, prior to the development of the ammoniation process in 1928, were superphosphate, triple superphosphate, and ammonium phosphate. The principal phos-

phatic component of ordinary and triple superphosphate is mono-calcium phosphate. On treatment of these materials with free ammonia, the monocalcium phosphate is changed into other phosphatic combinations depending on the percentage of ammonia added. According to Keenen (15) the principal phosphates formed in the ammoniation of ordinary superphosphate are dicalcium phosphate, tricalcium phosphate, and monoammonium phosphate. The reactions involved in the ammoniation of triple superphosphate differ somewhat from those that take place in the ammoniation of ordinary superphosphate, but the phosphate products formed on maximum ammoniation were represented by White, Hardesty, and Ross (45) to be the same compounds, viz., tricalcium phosphate, monoammonium phosphate, and dicalcium phosphate, as those which were claimed by Keenen to be formed on the complete ammoniation of ordinary superphosphate.

Two of the compounds formed in the ammoniation of superphosphate, namely, dicalcium phosphate and monoammonium phosphate, were well known fertilizer materials. Tricalcium phosphate, however, was recognized to be a new component of fertilizer mixtures, and little was known as to its true fertilizer value. An investigation was accordingly undertaken by Ross, Jacob, and Beeson (35) under the auspices of the Association of Official Agricultural Chemists to study the chemical and physical properties of this new fertilizer component and of its related compounds, and to find a laboratory method that would be applicable to the evaluation of ammoniated as well as of ordinary and triple superphosphates.

It was concluded from this investigation that the official method for evaluating phosphatic materials gave too low a rating, as a rule, to the phosphoric acid in ammoniated superphosphates, and it was recommended that the method be changed to the extent that a 1 gram sample be taken for analysis in place of 2 grams. The time of digesting the water-insoluble residue in the neutral ammonium citrate solution was increased from 30 minutes to 1 hour. These modifications of the method for evaluating phosphatic materials were adopted in 1932, and the modified method is now the official method of the Association (1947).

It is now well known that curing of an ammoniated fertilizer mixture involves reactions in addition to those that take place during ammoniation. The elevation in temperature that accompanies ammoniation increases the rate of reaction between the various components of a mixture and initiates reactions that do not normally occur at ordinary temperatures (6, 16). Thus MacIntire, Hardin, Oldham, and

Hammond (22) found that a moist mixture of tricalcium phosphate and calcium fluoride reacts to form fluorphosphate, which is new rock phosphate. The pulverulent calcium fluoride used in the mixture lost its petrographic identity, and the behavior of the synthetic fluora-patite formed corresponded to that of the natural apatite. It was con-cluded that tricalcium phosphate formed in the ammoniation of mixed fertilizers may react with the fluorine in the superphosphate to form fluorapatite, and that the formation of the fluorapatite may occur not only during the curing of processed superphosphates but also during their analysis.

Further evidence of the formation of fluorapatite in highly ammoni-ated mixtures is afforded by the experiments of MacIntire and Hardin (19), who found that the reversion of phosphoric acid in ammoniated superphosphates according to the present A.O.A.C. method is in pro-portion to the fluorine content. No reversion occurs, however, in the ammoniation of superphosphates that contain little or no fluorine. The calcium fluoride in superphosphate is usually sufficient to convert all the phosphorus present into fluorapatite (23).

It has also been shown by Ross, Rader, and Beeson (36) that the tri-calcium phosphate initially formed in the ammoniation of superphos-phate undergoes hydrolysis at ammoniation temperatures and in stor-age to form calcium hydroxyphosphate, and that the presence of dolo-mite increases the extent to which this reaction takes place, and that in the presence of fluorine the reaction apparently proceeds to the forma-tion of a fluorapatite, as suggested by MacIntire and coworkers (21, 22).

The percentage of the total phosphoric acid that exists in the phosphatic components of ammoniated superphosphates of varying ammonia content as calculated from Keenen's data (15) are reported in Table 21. It should be pointed out that with 2.3 percent ammoniated

Table 21.—THE CHANGES PRODUCED IN SUPERPHOSPHATE ON AMMONIATION.

Total Phosphoric acid[1]	Ammonia	Monocalcium phosphate	Dicalcium phosphate	Tricalcium phosphate	Ammonium phosphate
Percent	Percent	Percent of the phosphate present in the different forms			
17.49	0.0	86.0	14.0	0.0	0.0
18.66	2.3	5.5	39.1	2.5	52.9
18.26	3.3	0.0	28.0	21.3	50.7
17.86	4.2	0.0	11.1	47.4	41.5
18.07	5.0	0.0	0.0	65.9	34.1
17.11	6.0	0.0	0.0	81.6	18.4

[1]Omitting phosphate rock.

superphosphate the calcium phosphates listed contain considerably less calcium than the calcium phosphates in the unammoniated sample. It should also be pointed out that 2.3% ammonia is not sufficient to convert 52.9% of the phosphorus into ammonium phosphate. The data for 2.3 percent ammoniated superphosphate, therefore, do not appear to be reasonable.

On the basis of the work of MacIntire et al. (19, 21, 22, 23) the phosphate listed as tricalcium phosphate by Keenen (15) might actually exist as fluorphosphate. These authors point out that the reaction between tricalcium phosphate and calcium fluoride to form fluorphosphate varies with the temperature and the time of curing. The formation of fluorphosphate was suggested by MacIntire (18) and by MacIntire and Hatcher (23) to explain what happens ultimately to superphosphate incorporations in limed soils. Data were also presented from Rothamsted (England) which show that rock phosphate (apatite) is formed from superphosphate applied to highly limed soils (25).

At the time the change was made in the method for determining available phosphorus, the fertilizers used by farmers were largely acid-forming. The recommendation that the new procedure be adopted was based upon plant tests on soils having a pH of less than 6.0. The greenhouse data reported by Ross, Jacob, and Beeson (35) show that highly ammoniated superphosphate and tricalcium phosphate were very poor sources of phosphorus on seven soils of pH 6.0-7.0, on one soil of pH 6.6-7.6, and on one soil of pH 8.02. These data were not considered in changing the method for determining available phosphorus. Recent data presented by Cooper of South Carolina (8) show that 19.5 percent of the soils in that state are less acid than pH 6.0. From the data presented by Ross, Jacob, and Beeson (35) it is necessary to conclude that a method based on crop response to phosphorus on soils more acid that a pH of 6.0 is not applicable for soils less acid than a pH of 6.0.

Since the present A.O.A.C. method for determining available phosphorus was adopted, the fertilizer recommendations of the Southeast have almost invariably pertained to neutral fertilizers. When neutral fertilizers are used, the soluble acid-forming nitrogen-containing salts probably diffuse out of the zone of fertilizer application, leaving the phosphate in a zone less acid than pH 6.0. If fertilizers had been predominantly neutral in 1932 when Ross, Jacob, and Beeson (35) made their report, it is believed that they would have given more consideration to their greenhouse data on soils that were less acid than

pH 6.0, in which case they might not have approved the present method for determining available phosphorus.

As was pointed out by Ross, Jacob, and Beeson (35), the present official method has a very serious defect in that it indicates a higher availability for water-insoluble phosphates when present in mixtures than when undiluted by other materials, or when present in low analysis mixtures as compared with those that have a high phosphate content. Thus, Ross, Jacob, and Beeson (35) found that the citrate-insoluble phosphate in a 6.58 percent ammonia ammoniated superphosphate amounted to 19.1 percent of the total when the analysis was made by the present official method on the material as such; to 7.5 percent when it was used as the only source of phosphate in a 4-12-4 mixture; and to only 1.0 percent when it was used in a 4-6-4 mixture.

According to Keenan's data (above) more than 80% of the phosphorus in 6.58% ammonia ammoniated superphosphate was present as tricalcium phosphate, which according to the work of MacIntire and co-workers may have been converted into fluorphosphate or new rock phosphate. In fertilizers of low phosphorus content, apparently most tricalcium phosphate and new rock phosphate are determined as available by the official method for determining available phosphorus.

The chemical analysis of the superphosphates used in the experiments reported on pages 283-285 were made under the supervision of Dr. W. H. Ross of the Bureau of Plant Industry. Basing the superphosphate with 250 pounds of dolomite per ton reduced the value of the phosphate nearly 50% as measured by cotton production, and only 0.59% or 3.4% of the total as measured by the A.O.A.C. method for determining available phosphorus. The ammoniation of superphosphate reduced the value of the phosphorus by more than 50% as measured by cotton production, and only 1.38% or 7.7% of the total as measured by the A.O.A.C. method for determining available phosphorus. The chemical analyses were made on superphosphates containing about 18% phosphate; if they had have been made on mixed fertilizers containing 8% phosphate the loss in available phosphorus might have been negligible as suggested by data above.

Greenhouse and chemical data by Ross et al. were reported which show that the present method for determining available phosphorus is unsatisfactory for superphosphates ammoniated with 3 percent or more ammonia. Parker and Ross (28) recommended the use of as much as 3.75 per cent ammonia to the fertilizer manufacturers on the basis of 20% superphosphate, and stated that "many operators use sub-

stantially higher rates . . . .". Since the present official method was recognized by Ross et al. (33) as being unsuited for determining available phosphorus where 3 per cent or higher ammoniated superphosphate is used, it appears that it is also unsuited for determining available phosphorus in fertilizers where the rate of ammoniation is unknown.

In 1930 and 1931, when Ross et al. (34, 35) recommended that the size of the sample used for determining available phosphorus in phosphatic materials be reduced from two grams to one gram, they pointed out that "a 1-gram sample of ammoniated superphosphate is equivalent in P_2O_5[1] content to two grams of the average mixed fertilizer and the adoption of this procedure would call for a 2-gram sample as used at present" (1930) in the analysis of all materials containing ten per cent or less of total P_2O_5." Since most of the phosphorus sold to farmers is in mixed fertilizers, which contain ten per cent or less phosphoric acid, it appears that this recommendation would have been more nearly applicable than the present method.

Some question might therefore be raised as to the suitability of the present official method for determining the available phosphate in phosphatic materials. That it gives too high an availability rating to materials such as tricalcium phosphate when used in mixed fertilizers, and to highly ammoniated superphosphates, is suggested by results obtained in numerous field and greenhouse tests.

SUMMARY AND CONCLUSIONS

The data reviewed in this chapter on the response of crops to phosphorus and on the official method for determining available phosphorus in fertilizers show that:

1. Rock phosphate or waste pond phosphate is usually a poor source of phosphorus for most crops.
2. Superphosphate and triple superphosphate contain phosphorus in water soluble form, and they are always good sources of phosphorus.
3. The availability of phosphorus in dicalcium phosphate is open to question. In many tests it has been a poor second to more soluble sources of phosphorus; and in many other tests too much phosphate has been used to determine differences in the efficiency of the different sources.
4. Tricalcium phosphate is an inferior source of phosphorus for row crops even in strongly acid fertilizers on acid soils.
5. Basic slag is a good source of phosphorus for broadcast crops; it was generally inferior to superphosphate for cotton production.
6. The use of dolomite to make neutral fertilizers is a good practice

[1]Phosphate.

where the fertilizers are to be applied in a short time. There is some question concerning the desirability of making fertilizers neutral with dolomite some time in advance of application.

7. The ammoniation of superphosphate converts water soluble phosphorus into water insoluble dicalcium phosphate, tricalcium phosphate, and fluorphosphate (new rock phosphate). The water insoluble phosphates increase with increasing rates of ammoniation.

8. When the rate of ammoniation of superphosphate is as much as $2\frac{1}{2}$ per cent the efficiency of the phosphorus has been reduced in greenhouse experiments; and with 3 per cent, the efficiency has been reduced in field experiments. Phosphorus becomes increasingly less efficient as the rate of ammoniation increases.

9. The present official chemical method for determining available phosphorus in fertilizers is satisfactory for fertilizers containing phosphate derived from non-ammoniated and 2 per cent ammoniated superphosphates.

10. The present official chemical method for determining available phosphorus in fertilizers is not satisfactory for fertilizers containing phosphate derived from superphosphates ammoniated with 3 per cent or higher ammonia—basis 20 per cent superphosphate.

11. Recommendations and statements of U.S.D.A. officials indicate that the superphosphate (20 per cent basis) contained in mixed fertilizers may be ammoniated to 3 per cent or more ammonia.

12. There appears to be sufficient data available on the response of plants to phosphorus containing fertilizers of different and known chemical solubility to enable the establishment of a satisfactory method for determining available phosphorus in fertilizers.

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CHAPTER

(12)

The Response of Crops to Potash

and Soda

*The known supplies of easily minable potash in the United States may
last only 100 years at the present rate of consumption.*

The use of potash in fertilizers is an established practice in the
intensive farming regions of the world. The consumption, production
and importation of potash for agricultural and chemical uses in North
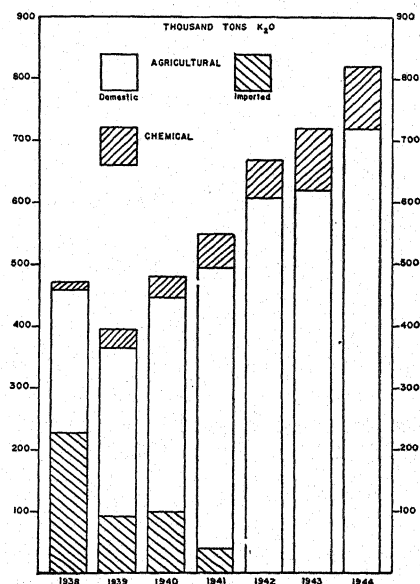
FIG. 1.—Potash deliveries in North America for
agricultural and chemical purposes. (Courtesy
American Potash Institute.)

America are illustrated in Figure 1. Before World War I North America
was dependent upon European supplies of potash. The 1940 price of
50% muriate of potash to farmers was $40 to $50 per ton. With

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foreign potash cut off during World War I, the price increased to more than $500 per ton (15)[1].

During World War I potash was manufactured in the United States (30) from:

1. Natural brines of Nebraska, Utah, and California.
2. Deposits of leucite in Wyoming.
3. Sea weeds off the coast of California.
4. Wood ashes in Michigan.
5. Greensand in New Jersey.
6. Dust from cement kilns and blast furnaces.
7. Waste liquors from sugar beet refineries and distilleries.

The amount of potash obtained from the above sources was small, and with the end of the war and the reentrance of European potash on the American market, the production of American potash declined until 1922, after which it increased. At the present time sufficient potash is being produced in this country (9) to supply the requirements.

In 1945 the world supply of potash was estimated at 5,000 million tons, while the United States' reserves which may be mined cheaply were estimated at 90 million tons. At the present rate of consumption the known supply of potash in the United States will last only about 100 years (33). If the consumption of potash should double in the next few years, which is not inconceivable, the known supplies would last only about 50 years.

Since the known supplies of potash in this country will last not more than 100 years, efforts should be made to locate additional supplies. If additional supplies of potash are not assured, consideration should be given to the preservation of our present supplies for use in periods of war when foreign supplies are unavailable.

Potash is being mined in the Permian Basin in New Mexico and Texas, near Carlsbad, New Mexico, from the salt flats of Utah and from the brines of Searles Lake, California. The potash bed in the Permian Basin is about 1000 feet below the surface (17). In the salt flats of Utah the potash is leached out of beds containing potash. From Searles Lake, brines are pumped from which, in addition to potash, borax and other salts are obtained (22). A preliminary estimate of the amount of potash salt available for mining in the Permian Salt Basin in 1933 was more than 100,000,000 tons (29). Searles Lake has been estimated to contain more than 36,000,000 tons of potash (30). The deposits of potash may be larger than the estimates.

[1]Numbers in parenthesis refer to the source of information, page 325.

Pure muriate of potash contains 63% potash. Potash as mined at Carlsbad, New Mexico, contains about 25% potash, and the impurity is largely table salt. Due to the long haul to the markets, the table salt is removed from the potash at the mines before shipping.

In 1946, the cost of muriate of potash containing 62½% potash at Carlsbad, New Mexico, was $22.50 per ton; manure salts containing 25% potash cost $5.00 per ton. These prices were subject to a 12% discount on orders placed in June for delivery before the end of the

POTASSIC FERTILIZERS
Prices per Unit K_2O
Bulk c.i.f.
Atlantic and Gulf Ports
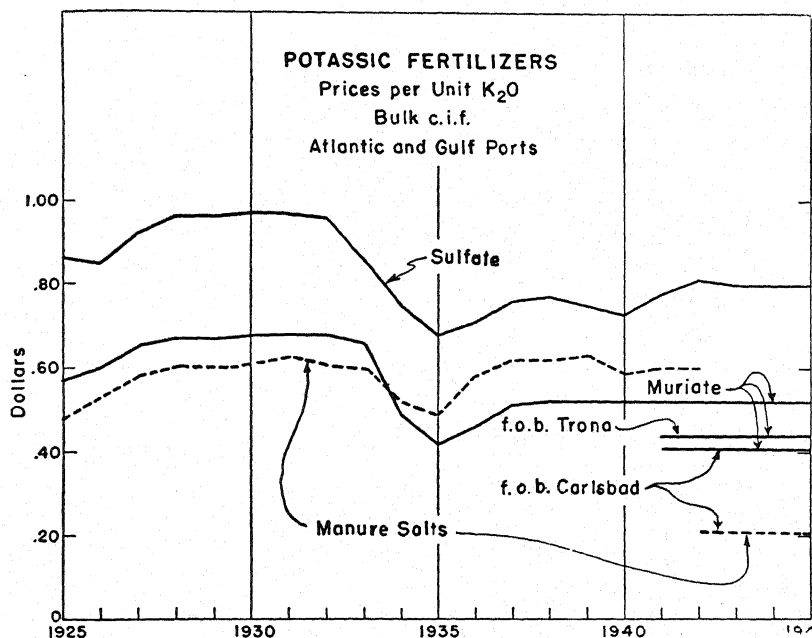
FIG. 2.—Wholesale price of 20 lbs. potash (K_2O) at Baltimore, Maryland. (Courtesy U.S.D.A.)

year. The wholesale price of 62% muriate of potash at ports was $33.44, and, after the discount of 12%, which is usually taken, the price was $29.43. The Office of Price Administration price in Mississippi was $51.80 in 1945. The cost of getting a ton of muriate of potash to the farmer was $22.37 as compared to approximately $12.00 for a ton of nitrate of soda. The cost of potash in manure salts at the mine is considerably less than that of potash in high grade muriate of potash. The difference in cost is due to the cost of refining the manure salts to make high grade muriate of potash. The cost of bags is about $2.00 per ton. The wholesale cost of potash in bags without tags in high grade muriate of potash and in manure salts should be equal where the

freight is $5.81 per ton. It appears that manure salts will not be used except where a need for table salt is recognized. Manure salts causes mixed fertilizers to take up more water, and induces less desirable physical properties. Manure salts has a place for car lot buying by farmers where a car of high grade muriate of potash would be too much, and where crops respond to table salt.

One ton of 62½% muriate of potash cost $19.80 with all discounts taken at Carlsbad, New Mexico in 1945; the same amount of potash could be bought as manure salts for $11.00. With an estimated freight and bagging cost of $14.00 per ton, the cost becomes $33.80 for 62½% muriate of potash and $46.00 for 2½ tons of manure salts. With 20% added for handling charges, the cost becomes $40.56 and $55.20, respectively. Subtracting $40.56 from $55.20 gives $14.64 as the cost of the 1½ tons of table salt in the manure salts, or a cost of approximately $10 per ton of table salt. If the indicated retail price prevailed, a much greater tonnage of manure salts might be used.

Most of the potash shipped from the mines in the United States in 1940 contained 60 to 63% potash. The average potash content of all potash fertilizers sold in the fertilizer trade was 58%. High grade muriate of potash containing 62 to 63% potash is diluted with filler to make so-called muriate of potash, which contains 50% potash, and so-called kainit, which contains 20% potash. The filler is usually sand or dolomite. Each ton of 50% muriate of potash which is made from 62.5% muriate of potash contains 400 pounds of filler; each ton of 20% kainit which is made from 62.5% muriate of potash contains 1,360 pounds of filler. The cost of filler in potash fertilizers to the farmer has been about $15.00 per ton.

Diluting one ton of 62.5% muriate of potash with 2.12 tons of filler to make so-called kainit adds approximately $30.00 to its cost. If the filler used were dolomitic limestone, it could be bought for about $4.00 per ton. Except with those crops where unrefined manure salts are more effective than high grade muriate of potash, it is more economical to buy potash containing 60% potash.

Sulphate of potash is preferred to muriate of potash for tobacco. Too much chlorine in fertilizers produces tobacco of poor burning quality. Sulphate of potash is produced by treating muriate of potash with sulphuric acid (13); consequently, the cost of potash in sulphate of potash is greater than that in muriate of potash. Sulphate of potash is obtained from certain mines. If potassium metaphosphate can be produced at a price which will warrant its use as a fertilizer, it could at least partially replace sulphate of potash in tobacco fertilizers.

Potassium metaphosphate is produced by burning phosphorus in the presence of muriate of potash. Potassium metaphosphate does not contain chlorine or sulphur, which tend to deplete the soil of potash and other bases. From the standpoint of the nutrients, potash and phosphorus, potassium metaphosphate should be equal to other sources of potash. Although the limited amount of data available is not conclusive, potassium metaphosphate shows promise of being a good source of phosphorus and potash.

Sulphate of potash magnesia is a mixture of potassium sulphate and magnesium sulphate, which has very little chlorine. It is a good source of soluble magnesium as well as potash. It usually contains about 25% potash and 25% magnesia.

Sulphate of potash contains 48% potash. It is usually used on tobacco, where only a small amount of chlorine is desirable.

Potassium nitrate contains 13% nitrogen and 44% potash.

Manure salts contains about 40% muriate of potash and 55% or more table salt. The potash content usually varies between 23 and 30%.

Kainit is a low grade, unrefined potash fertilizer. The French kainit contains table salt as an impurity (13). Some kainit contains considerable magnesium sulphate. Differences in yields of crops produced by different kainits have been observed by farmers. Preference based upon experience has been expressed in favor of red kainit. The red kainit is reported to have contained magnesium sulphate. The appearance of red colored particles in fertilizers containing potash is due to iron oxide. The iron oxide in fertilizers containing potash has no plant nutrient value.

The response of seven crops to soda supplied by table salt is shown by the data (11) reported in Table 1. The crops were grown in sand in the greenhouse. Cotton, sugar beets, and turnips were the most responsive crops to soda; oats and wheat were intermediate, while vetch and Austrian winter peas were least responsive to soda.

On the basis of the average data, almost equal increases in yield were obtained from soda with all rates up to 72 pounds of potash per acre. With 144 pounds of potash per acre, little response to soda was obtained.

The data on the average of all crops presented in Figure 3 show that the plants contained much higher quantities of soda where low amounts of potash were applied. The potash content of the plants increased as the rate of application of potash increased.

The data presented in Figure 2 show that the use of soda actually

had little if any effect on the potash content of the plant at a particular rate of application of potash, which suggests that "the application of the soda enabled the plants to recover additional potash from the sand in which they grew, a relative amount which is indicated approximately by the increases in yield, due to the application of soda" as shown in Table 1.

Table 1.—Yields of Plants Grown in Greenhouse Sand Cultures Fertilized With Different Amounts of Potash, Both With and Without Soda.

Pot No.	Lbs. of potash applied per acre[1]	Lbs. of dry matter per acre			Percentage increase due to soda	Lbs. of dry matter per acre			Percentage increase due to soda
		Minus soda	Plus soda	Increase due to soda		Minus soda	Plus soda	Increase due to soda	
		Cotton				Oats			
1	0	636	1,818	1,182	185.8	2,897	4,254	1,357	46.8
2	9	1,091	2,000	909	83.3	4,435	6,426	1,991	44.9
3	18	1,818	3,273	1,455	80.0	4,706	8,371	3,665	77.9
4	36	3,818	4,818	1,000	26.2	5,340	9,503	4,163	78.0
5	72	6,364	6,636	272	4.3	8,190	9,955	1,765	21.6
6	144	7,636	7,818	182	2.4	8,552	10,498	1,946	22.8
		Vetch				Austrian winter peas			
1	0	5,159	6,154	995	19.3	3,711	4,344	633	17.1
2	9	6,426	6,697	271	4.2	4,887	5,973	1,086	22.2
3	18	6,788	7,240	452	6.7	5,611	5,973	362	6.5
4	36	7,512	8,326	814	10.8	6,788	6,969	181	2.7
5	72	8,508	9,096	588	6.9	8,154	8,417	272	3.3
6	144	8,598	9,096	498	5.8	9,774	9,322	0	0
		Wheat				Sugar beets			
1	0	6,607	10,951	4,344	65.7	1,318	2,909	1,591	120.7
2	9	8,145	10,860	2,715	33.3	2,182	4,682	2,500	114.6
3	18	8,960	10,770	1,810	20.2	3,000	6,545	3,545	118.2
4	36	9,774	11,765	1,991	20.4	3,909	7,273	3,364	86.1
5	72	10,408	12,942	2,534	24.3	5,000	8,000	3,000	60.0
6	144	11,313	12,761	1,448	12.8	7,364	9,318	1,954	26.5
		Turnips				Average for seven crops			
1	0	742	1,720	978	131.8	3,010	4,593	1,583	52.6
2	9	1,720	2,987	1,267	73.7	4,127	5,661	1,534	37.2
3	18	2,350	3,439	1,089	46.3	4,748	6,516	1,768	37.2
4	36	3,349	4,435	1,086	32.4	5,784	7,584	1,800	31.1
5	72	4,616	5,068	452	8.9	7,319	8,588	1,269	17.3
6	144	5,702	5,887	185	3.2	8,420	9,243	823	9.8

[1] Adequate amounts of other required nutrients were supplied. Table salt was applied at the rate of 1,113 pounds per acre.
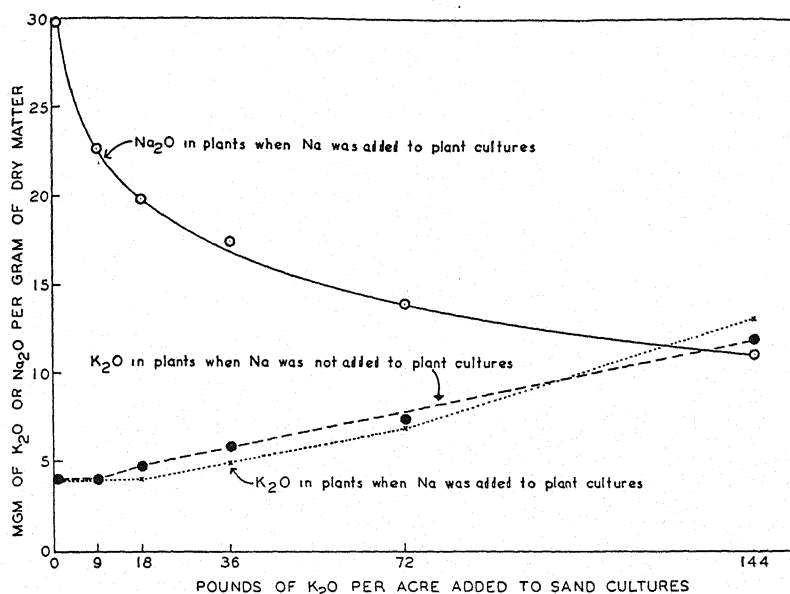
FIG. 3.—The effect of soda (Na_2O) as table salt (NaCl) and potash (K_2O) on the soda ash (Na_2O) and potash content of seven crops (cotton, oats, wheat, sugar beets, vetch, Austrian winter peas, and turnips (11). (Cut courtesy American Society of Agronomy.)

The effect of table salt on the yield of truck crops on muck soil (5) is shown by the data reported in Table 2. The yield of table beets, turnips, celery, mangels, Swiss chard, cabbage and sugar beets was increased considerably by the application of table salt. The response to table salt was obtained where 216 pounds of potash was applied per acre.

Table 2.—THE RESPONSE OF TRUCK CROPS TO TABLE SALT.

Crop	Years	Pounds of table salt		
		None	500	1000
		Yield—tons per acre		
Table beets...............	6	10	19	22
Turnips..................	4	10	14	16
Celery...................	6	18	24	25
Mangels.................	2	12	24	31
Swiss chard..............	2	18	27	31
Sugar beets..............	6	8	12	12
Cabbage.................	1	30	34	36

Crops were classified on the basis of their response to salt by Harmer of Michigan (5) as shown in Table 3.

Table 3.—RESPONSE OF CROPS TO TABLE SALT.

High response	Medium response	No response
Celery	Cabbage	Asparagus
Mangels	Celeriac	Barley
Sugar beets	Kale	Broccoli
Swiss chard	Kohlrabi	Brussels sprouts
Table beets	Radish	Carrots
Turnips	Rape	Corn
		Lettuce
		Oats
		Onions
		Parsley
		Parsnips
		Peppermint
		Potatoes
		Spinach
		Tomatoes

The response of 12 crops to sources of potash in Rhode Island (24) is shown by the data presented in Table 4. In general muriate of potash was equal to, or slightly superior to, sulphate of potash or sulphate of potash—magnesia. Kainit was superior to muriate of potash for sweet clover, tomatoes, onions, squash, cabbage, and mangels. Since lime containing magnesium was applied to the soil the superiority of kainit to muriate of potash was due to the soda in the table salt it contained. The average relative response to potash was muriate 100, kainit 111, sulphate 94, and sulphate of potash magnesia 95.

Kainit produced 11% more than muriate of potash on the basis of all crops. Tomatoes, onions, rutabagas, squash, cabbage, and mangels were particularly responsive to kainit. Grass, sweet clover, alfalfa, red top, timothy, potatoes, and parsnips gave less yield with kainit than with muriate of potash.

Manure salts is an excellent source of potash for cotton as shown by data from South Carolina (38), which are reported in Table 5. Manure salts produced more cotton than muriate of potash in the above test. Data from other tests (Chapter 1) show that mangolds, sugar beets, tobacco, and other crops respond to sodium. Where crops respond to table salt, manure salts is more valuable than high grade muriate of potash. However, the soil conditions under which crop response to table salt is obtained are not well known.

The data on the response of cotton to sources of potash reported

Table 4.—THE RESPONSE OF TWELVE CROPS TO SOURCES OF POTASH.

Crops	Lbs. potash applied	Source of potash			
		Muriate	Kainit	Sulphate	Sulphate potash-magnesia[1]
		Yield per acre			
Grass and sweet clover....	50	1.87 tons	2.51 tons	1.88 tons	2.03 tons
Grass, alfalfa and clover...	50	3.88 tons	3.98 tons	3.49 tons	3.41 tons
Timothy—red top........	44	1.88 tons	1.88 tons	1.99 tons	1.91 tons
Timothy—red top........	40	1.28 tons	1.14 tons	1.29 tons	1.25 tons
Timothy—red top........	40	2.48 tons	2.23 tons	2.28 tons	2.64 tons
Av. 5 crops—5 different yrs.	...	2.18 tons	2.37 tons	2.19 tons	2.29 tons
Potatoes.................	50	194 bus.	180 bus.	208 bus.	193 bus.
Potatoes.................	75	165 bus.	194 bus.	185 bus.	143 bus.
Potatoes.................	100	383 bus.	323 bus.	393 bus.	302 bus.
Potatoes.................	100	323 bus.	340 bus.	366 bus.	336 bus.
Potatoes.................	100	209 bus.	142 bus.	238 bus.	219 bus.
Av. 5 crops—5 different yrs.	...	255 bus.	236 bus.	278 bus.	239 bus.
Tomatoes (ripe)..........	50	249 bus.	440 bus.	310 bus.	375 bus.
Tomatoes.................	75	52 bus.	99 bus.	54 bus.	40 bus.
Tomatoes.................	100	683 bus.	754 bus.	663 bus.	571 bus.
Tomatoes.................	100	411 bus.	412 bus.	463 bus.	450 bus.
Av. 4 crops—4 different yrs.	...	349 bus.	426 bus.	372 bus.	359 bus.
Carrots..................	75	1068 bus.	936 bus.	912 bus.	894 bus.
Carrots..................	100	978 bus.	982 bus.	871 bus.	882 bus.
Carrots..................	100	577 bus.	621 bus.	545 bus.	519 bus.
Av. 3 crops—3 different yrs.	...	874 bus.	846 bus.	766 bus.	765 bus.
Onions...................	100	583 bus.	619 bus.	638 bus.	642 bus.
Onions...................	100	226 bus.	281 bus.	193 bus.	227 bus.
Av. 2 crops—2 different yrs.	...	404 bus.	450 bus.	415 bus.	434 bus.
Rutabagas...............	50	655 bus.	739 bus.	522 bus.	598 bus.
Parsnips.................	50	810 bus.	577 bus.	592 bus.	599 bus.
Parsnips.................	75	564 bus.	558 bus.	705 bus.	528 bus.
Av. 2 crops—2 different yrs.	...	680 bus.	567 bus.	648 bus.	563 bus.
Squash..................	75	2.25 tons	2.93 tons	2.25 tons	1.46 tons
Cabbage.................	50	298 bbls.	370 bbls.	254 bbls.	256 bbls.
Cabbage.................	75	422 bbls.	483 bbls.	354 bbls.	332 bbls.
Av. 2 crops—2 different yrs.	...	360 bbls.	432 bbls.	304 bbls.	294 bbls.
Oats....................	44	28.1 bus.	27.6 bus.	28.1 bus.	21.5 bus.
Barley..................	75	15.07 bus.	16.57 bus.	13.80 bus.	12.82 bus.
Mangels.................	100	22.5 tons	26.85 tons	17.25 tons	15.45 tons
Mangels.................	100	13.14 tons	24.00 tons	8.77 tons	7.92 tons
Av. 2 crops—2 different yrs.	...	17.82 tons	25.42 tons	13.01 tons	11.68 tons

[1]Magnesium supplied in liming materials.

Table 5.—The Response of Cotton to Potash and Lime.

	8-year average yield of seed cotton, pounds per acre	
	Unlimed	Limed
No potash..................................	120	107
240 pounds manure salts.....................	784	1037
100 pounds muriate of potash................	701	958

in Table 6 were collected in North Carolina (21). These soils were very responsive to potash. Kainit was superior to muriate of potash and sulphate of potash. The superiority of kainit to the other sources of potash is attributed to the table salt in kainit. Sulphate of potash-magnesia produced as much seed cotton as kainit at the low rate of application.

Table 6.—The Response of Cotton to Sources of Potash.

Potash		Increase in yield—lbs. seed cotton per acre			
Source	Pounds per acre	Test 1	Test 2	Test 3	Average
Kainit.....................	25	275	230	585	354
Muriate of potash...........	25	235	190	420	282
Sulphate of potash-magnesia..	25	255	260	580	365
Sulphate of potash...........	25	125	180	240	182
Kainit.....................	50	555	250	530	445
Muriate of potash...........	50	335	295	410	347
Sulphate of potash-magnesia..	50	170	385	475	343
Sulphate of potash...........	50	180	270	475	308

The response of cotton to sources of potash is shown by data (1) reported in Table 7. When kainit was superior to muriate of potash,

Table 7.—The Response of Cotton to Sources of Potash.

Source of potash	Increase in yield, pounds of seed cotton per acre		
	Test 1 6 years	Test 2 5 years	Test 3 2 years
Muriate of potash 60%.................	342	405	...
Muriate of potash 50%.................	...	451	397
Sulphate of potash.....................	433	434	497
Kainit................................	427	556	379
Nitrate of soda potash..................	...	399	...
Manure salts..........................	...	...	390
Sulphate of potash magnesia.............	...	...	436

its superiority was probably due to the magnesium sulphate or table salt it contained.

The response of cotton to sources of potash in North Carolina (25) is shown by the data in Table 8. The soil was a sandy loam. Sulphate

Table 8.—THE RESPONSE OF COTTON TO SOURCES OF POTASH.

Source of potash	Treatment—600 pounds of fertilizer		
	4-7-0	4-7-2	4-7-4
	Yield—lbs. seed cotton per acre		
	First year		
Muriate..........................	1268	1502	1619
Sulphate........................	1268	1496	1450
Kainit..........................	1268	1520	1610
	Second year		
Muriate..........................	1045	....	1331
Sulphate........................	1045	1397	1298
Kainit..........................	1045	....	1198

of potash produced about the same yield as the other sources except with the higher rate in the first year. Kainit produced less cotton during the second year than the other sources.

Sweet potatoes gave less response to kainit than to other sources of potash (28) in North Carolina (average of 6 tests):

Source of potash	Yield—bushels of potatoes per acre
Sulphate............................	148
Muriate.............................	142
Kainit..............................	94

The reduced yield with kainit is attributed to injury produced by the table salt it contained. The potash in kainit is in the same form as that in muriate of potash. The difference is that 300 pounds of 20% kainit would contain about 200 pounds more table salt than 100 pounds of high grade muriate of potash.

Muriate of potash was more effective than sulphate of potash for celery production in Florida (27), where 8,000 pounds of 5-6-6 fertilizer was used per acre:

Source of potash	Yield—crates of celery per acre
Sulphate...................................	511
Muriate....................................	574

Since the test was conducted on a sand soil under high rainfall, the difference in the yield of celery due to sources of potash may have been due to the differences in leaching of potash from the two sources (Chapter 4). In the case of muriate of potash the chlorine would tend to be lost as calcium chloride, leaving the potash on the clay; in the case of potassium sulphate, the tendency would be for potassium sulphate, rather than calcium sulphate, to leach out of the soil.

Muriate of potash was more effective than sulphate of potash and manure salts for potatoes (39) in eastern North Carolina:

Source of potash	Yield—bushels of potatoes per acre				
	1929	1930	1931	1932	Average
Sulphate.................	273	211	266	264	254
Manure salts..............	229	208	253	260	238
Muriate..................	293	238	275	291	274

The inferiority of manure salts may be due to the table salt which it contained.

The response of tobacco to sources of potash is shown by data from Maryland (20), which are reported in Table 9. The data show

Table 9.—THE RESPONSE OF TOBACCO TO SOURCES OF POTASH.

Sources of potash	Pounds of potash per acre		
	24	48	168
	Increase in yield—lbs. per acre		
Sulphate of potash...............	116	130	164
Muriate of potash...............	227	287	348
	Increase in value—dollars per acre		
Sulphate of potash...............	56	99	148
Muriate of potash...............	93	92	94
	Burning quality—duration of glow in seconds		
Sulphate of potash...............	8.0	11.5	25.7
Muriate of potash...............	3.6	3.2	1.8

that muriate of potash produced a higher yield of tobacco; however, the value of the tobacco receiving sulphate of potash was much higher than that receiving muriate of potash when used at the high rate. In this test, there was little difference in the value of the tobacco when 24 or 48 pounds of potash per acre was used.

The burning quality of the tobacco as measured by duration of the glow in seconds was always much higher with sulphate of potash. High potash content of tobacco is favorable to good burning quality; while a high chlorine content causes the burning quality to be poor.

Crops have been partially classified as to their response to potash (6), low potash response crops: oats, rye, wheat, millet and carrots; medium potash response crops: barley, rutabagas, parsnips, potatoes, and cabbage; high potash response crops: tomatoes, mangels, buckwheat, corn, and onions.

The author would put corn in the low potash response group, and add cotton to the high response group. As was pointed out in Chapter 8 the yield of crops harvested from land determines the amount of potash removed. It appears that the response of crops to potash when grown continuously and harvested will depend upon the amount of potash removed in the harvested crop.

The amount of potash in plants is a characteristic of the plant. The potash content of different plants varies, but certain plants are relatively high in potash and others are low in potash when grown under the same conditions. Differences in the potash content of plants (23) grown together for 56 days are shown by the following data:

Plant	Potash content
	Percent
Sunflower	4.2
Beans	1.4
Wheat	5.0
Barley	4.9

The potash content of beans was one-fourth to one-third as much as that of sunflowers, wheat, and barley.

Side dressing corn with potash produced satisfactory increases in the yield in Tennessee on a dry year (40). The potash was applied in a furrow about two inches deep (Table 10). The data suggest that the potash should be applied about 40 days after planting; however, satisfactory increases in yield were obtained when potash was applied 59

Table 10.—GRAIN YIELDS OF POTASH STARVED CORN WHEN FERTILIZED WITH POTASH AT DIFFERENT RATES AND ON DIFFERENT DATES, 1944.

Potash applied per acre	Time of application		
	40 days after planting, June 14	*59 days after planting, July 3*	*73 days after planting, July 17*
Pounds	*Yield—bus. corn per acre*		
0	3.7	8.7	8.1
25	15.9	21.4	11.1
50	27.9	21.9	10.2
100	30.8	26.4	14.9

days after planting. With a deeper application a deficiency of potash for corn might be corrected with later dates of application.

Side dressing cotton with potash on the surface of the soil was inferior to preplanting applications (36) in 12 tests in Alabama, in which a total of 60 comparisons was made (Table 11). The surface applied potash apparently did not get down to the roots. Side dressing with potash should be satisfactory where it is applied 4 or 5 inches deep.

Table 11.—THE YIELDS OF SEED COTTON OBTAINED FROM POTASH APPLIED AHEAD OF PLANTING AS COMPARED WITH YIELDS OBTAINED FROM POTASH APPLIED AS A SIDE-DRESSING AFTER THE COTTON WAS 3 TO 4 WEEKS OLD.

Pounds of potash applied per acre			*Pounds of seed cotton per acre*	
Under cotton	*Side dressed*	*Total*	*Yield 12 tests*	*Increase in favor of applying potash ahead of planting*
24	0	24	846	94
0	24	24	752	
48	0	48	1,074	160
24	24	48	914	..
48	0	48	972	113
12	36	48	859	..
72	0	72	1,117	35
24	48	72	1,082	..
72	0	72	941	130
12	60	72	811	..

Side dressing cotton with one-half of the potash where high rates are used on sandy soils is sometimes superior to applying all of the potash under cotton. The increase in yield for applying one-half of the potash as a side dressing over applying it all under cotton is shown by the following data from South Carolina (37):

Pounds potash applied per acre	1931	1932	1933	1934	1935	1936	1937	1938	Average
	Increase for applying one-half of the potash as a side dressing—lbs. seed cotton per acre								
15	−8	48	−4	61	38	−19	107	200	53
30	152	49	48	23	66	43	82	104	71
45	−19	5	68	−16	32	14	−6	156	29
60	93	29	−21	70	45	8	−20	81	35

The average increase in yield for side dressing with one-half of the potash for 15, 30, 45, and 60 pounds of potash was 53, 71, 29, and 35 pounds of seed cotton per acre, respectively. The advantage of side dressing with one-half of the potash was probably due to getting part of the potash away from the sulphur contained in the rest of the fertilizer, and the difference should be greater with increasing quantities of sulphur in the fertilizers (See page 95). In the above test, other data were obtained which show that applying all of the potash at chopping time was just as effective as applying it before planting.

When potash is used as a side dressing, it should be applied 3 to 4 inches deep so that it will be in moist soil where roots are present. Except where large amounts of acid elements are present, potash combines with the clay and does not leach badly. Most of the time when potash is used as a side dressing, it is applied on the surface of the soil, and very little good is obtained from it except on sandy soils, because the clay holds it and it does not go down to the plant roots. If potash were applied 3 to 4 inches deep while the plants are young, side dressing should be as effective as applying it before planting the crop.

The percentage recovery of potash applied to soils by plants is low. A recovery of 15% of the applied potash in seed cotton on soils badly deficient in potash is high, and more than 10% recovery is not often obtained where the potash requirement of a crop like cotton is met. The average recovery of potash in seed cotton is less than 5% of that applied. The recovery of potash is much higher in crops where most of the plant is harvested. It is doubtful if over 50% of the potash applied can be recovered over a period of years, even with crops which remove large amounts of potash. The data on this subject are limited.

The failure of crops to recover a large percentage of the applied potash is due to leaching of potash out of the soil and to the formation of potash mineral, from which potash is released slowly. The leaching

of potash is discussed in Chapter 4. It was pointed out that potash applied in the drill with other fertilizers containing high amounts of sulphates and other salts leached badly. One set of data suggests that potash should be applied broadcast; however, broadcast application of potash has not proven to be generally practicable.

Large amounts of potash may be tied up in an unavailable form by wetting and drying soil (32), which suggests that potash should be applied deep enough in the soil to be maintained moist. Where surface applications are made, the clay in the surface may absorb large amounts of potash, which becomes less available to plants through wetting and drying. Where potash is applied in soil which is maintained moist, it is doubtful if the formation of insoluble potash minerals is significant. Unfortunately, most investigations on the fixation of potash in an unavailable form have been made on soils which have been dried. Convincing proof that large amounts of potash are fixed in a form unavailable to plants under field conditions has not yet been presented.

The fate of potash applied to the soil for cotton production is suggested by data (12) presented in Table 12. The increases in yield

Table 12.—THE FATE OF POTASH APPLIED IN COTTON PRODUCTION.

Soil series	Years of test	Pounds per acre					Percent of applied potash not accounted for
		Increase in yield for period	Potash				
			Applied	In cotton	In soil, available[1]	Not accounted for	
Grenada.....	15	1,455	360	17	66	277	77
Hyman......	15	7,305	360	88	47	225	63
Ochlocknee..	15	5,340	360	64	47	249	69
Brandon....	5	2,355	120	28	0	92	77
Olivier.......	5	1,780	200	21	56	123	62

[1]Exchangeable.

of seed cotton were large, and only a small percentage of the applied potash was recovered in the seed cotton. Only a small amount of the applied potash remained in the soil in a form considered available to plants. Approximately two-thirds of the applied potash was not accounted for. The loss of potash, not accounted for, by leaching is logical; however, the fixation of potash in an unavailable form in the soil has been suggested.

The loss of potash by leaching is considerable under a wide range

of conditions. With a rainfall of 32 inches, 16 of which leached through the soil, the drainage water leached from 34 to 72 pounds of potash per acre out of the soil each year in New York (2). With an average rainfall of 34 inches per year in Scotland (10), with 18 inches leaching through the soil, only about 10 pounds of potash per acre leached out in the drainage water. The unusually low amount of potash lost from the Scottish soil by leaching was associated with a remarkably high loss of soda. It has been shown that soda reduces the loss of potash by leaching, which may account for the low amount of potash leached in the Scotland test.

Where 996 pounds of potash was applied to tobacco over a five-year period in Connecticut (see page 83), 879 pounds of potash was recovered in the drainage water and 262 pounds in the tobacco crop where sulphate of ammonia was applied. Less potash was leached with other sources of nitrogen.

Lipman of the New Jersey Agricultural Experiment Station made a study (14) of the loss of plant nutrients from the soil in which he concluded that the average loss of potash from harvested crop acres by leaching is 45 pounds per acre each year.

Approximately one-third of the potash mixed with the surface one and one-half inches of soil in pots and kept moist for 12 months was removed by two and one-half inches of leaching water in Delaware (8). The potash was applied with superphosphate to a sandy soil, and the sulphate from the superphosphate was probably largely responsible for the potash removed by leaching. The large loss of potash from sandy soil through which water leaches readily contrasts sharply with the loss from a heavy soil at Rothamsted, England, which requires tile drainage for successful crop production (7). On the heavy soil in England one half of the potash applied over a fifty-year period which was not recovered in the harvested crops remained in the surface nine inches of soil.

Over a 10-year period, 17 pounds of potash per acre per year was leached out of an acid fine sandy loam soil in a tank without potash treatment in Tennessee (18). Where 200 pounds of potash per acre was applied per year, after five years the loss of potash by leaching was equal to the annual application of potash. The use of lime at the rate of 2 tons per acre reduced the loss of potash by leaching about 300 pounds over the 10-year period. The value of 300 pounds of potash is considerably greater than the cost of limestone. The application of lime to an acid silt loam soil reduced the loss of potash by leaching, similarly. On an alkaline soil the application of lime reduced the loss

of potash only slightly, which would be expected. The loss of potash by leaching from different rotations including green manure crops varied from 13 to 26 pounds of potash per acre each year in South Carolina (26).

The relative importance of the loss of lime and potash in soil particles and in solution in the major streams is illustrated by data from Tennessee (31). The soil particles contained calcium and magnesium equal to 32 pounds of lime and one-half pound of potash in an available form, while the water in the rivers contained 348 pounds of lime and 7 pounds of potash per acre each year. The loss of these nutrients in an unavailable form in the soil particles is not considered to be of economic importance because the remaining soil contains similar quantities of these nutrients in a similar form. However the nutrients contained in solution are a direct loss from the soil.

The rivers of Tennessee carried 23.2 inches of water per acre of surface drained. If the rivers (3) of the Southeast carry 23.2 inches of water for the surface drained, each acre of land loses 12 pounds of potash and 120 pounds of lime each year. The value of the potash is 48 cents, while that of the lime is only 28 cents per acre.

The data presented suggest that the loss of potash by leaching from well drained soils is significant, and that the loss of potash from heavy or poorly drained soils by leaching is of less importance. Since most cultivated soils are sandy and silt loams, they are well drained, and in humid climates, where most potash fertilizers are used, it may be assumed that substantial quantities of potash are lost by leaching. The number of springs in an area is a direct indication of the leaching which takes place. It appears that the leaching of potash and other plant nutrients out of the soil is serious in any area which contains a considerable number of springs.

Searles Lake, California, is a notable example of the significance of the loss of potash by leaching. The Searles Lake deposit from which potash is mined covers an area of less than 12 square miles or about 7500 acres (22) (Figures 4, 5). It is a bed of salts which is 60 to 70 feet deep. About 25% of the volume of this bed is occupied by brines containing about 4.82% muriate of potash or a total of about 12,000,000 tons. The solid salts contain about twice as much total potash as the brine. There are several sodium salts in solution, amounting to 30% by weight.

The rainfall of the area is about 4 inches per year, which is much less than the normal evaporation. During the winter months sufficient water from the surrounding mountains runs into the lake to raise the
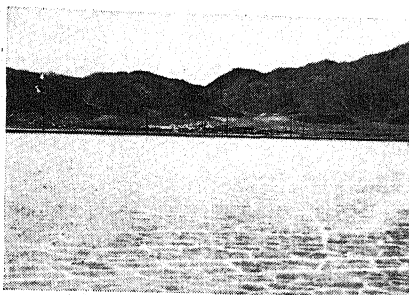
FIG. 4.—View of Searles Lake, California, from which muriate of potash is obtained. (Courtesy American Potash Institute.)

brine-water level to six inches above the top of the salt bed; during the summer evaporation lowers the brine-water level to six inches below the top of the salt bed. The potash and other salts in this lake have been brought in by the water. They were leached out of the soil from which the water came.

The effect of lime on the available potash in the soil has received considerable attention. It has been suggested, but there is a little evidence indicating, that liming increases the fixation of potash in a form which is unavailable to plants (35). Lime reduces the amount of potash which comes off of the clay into the soil solution. This reduction in the amount of potash which comes into solution increases

FIG. 5.—View of Searles Lake, California, showing the relation of brine and solid salts. (Courtesy American Potash Institute.)

the amount of potash which is available to plants by reducing its loss by leaching. Over-liming has induced potash deficiency in a few cases.

The use of lime, which increases the yield of crops which are harvested, reduces the available potash in the soil, due to the increased removal of potash in the crops, and most reductions of available potash produced by liming should probably be attributed to increased removal of potash in the higher crop yields rather than to the fixation of potash in an unavailable form. When several hundred pounds of lime is applied in the drill with a few hundred pounds of complete fertilizer, lime may induce potash deficiency, due to reduced solubility of the potash. Large amounts of lime should not be applied in the drill with complete fertilizers.

Soils which are naturally high in lime are usually naturally high in available potash. Since lime tends to keep potash on the clay (16, 19, 35), it keeps it from leaching out of the soil, and as a result the potash content of high lime soils is maintained at a higher level.

Acid elements, like sulphate, chloride, and nitrate, are constantly leaching out of the soil, and they take calcium, magnesium, and potash out with them. If large amounts of calcium and magnesium are maintained in the soil by liming, the probability of losing potash with these acid elements is reduced considerably. Normally large amounts of sulphur are present in mixed fertilizers; and since magnesium sulphate is very much more soluble than potassium sulphate, the presence of large amounts of magnesium in the soil should reduce the leaching of potash as the sulphate. Since potash costs about 20 times as much as lime, the economy of liming to conserve potash appears evident. Where calcium is supplied as calcium nitrate in fertilizers, it does not
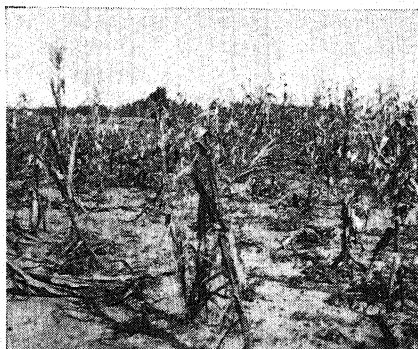
FIG. 6.—Corn breaks down badly where potash is extremely deficient. (Courtesy North Carolina Agricultural Experiment Station.)
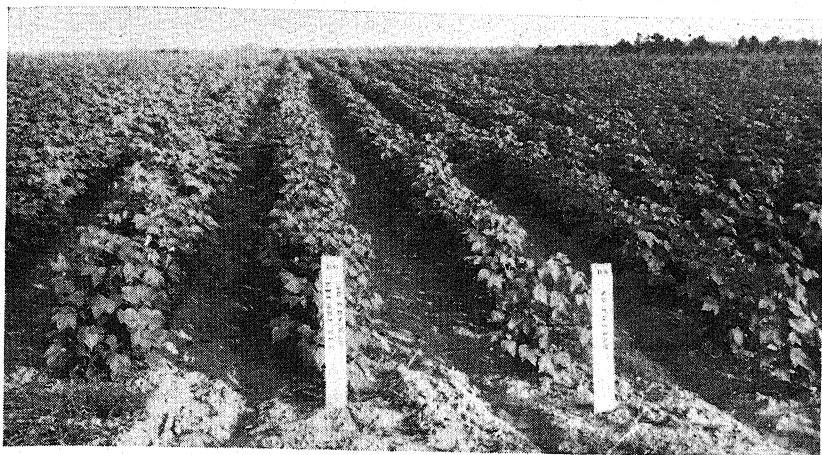
Fig. 7.—An early stage of potash deficiency for cotton. (Courtesy South Carolina Agricultural Experiment Station.)

protect potash, and apparently increases its loss by leaching (Chapter 4).

The available potash in the soil may be sufficient for corn where potash gives large increases in the yield of cotton. In Mississippi corn and sorghum gave no response to potash on soil on which potash had previously increased the yield of seed cotton 400 to 500 pounds per acre. The yield of corn was 60 bushels per acre. Potash made the corn grow off more rapidly, but it did not affect the yield of ear corn.

Potash deficiencies for corn are rarely found in the Southeast, where only small acreages of hay crops are grown. They are more often reported in the Middlewest and Northeast, where large acreages of hay crops are grown.

An extreme deficiency of potash is recognized by the presence of cotton rust, premature dying, and failure of the bolls to open properly (Figures 7, 8, 9). Extreme deficiencies of potash are rare. Plant symptoms of potash deficiencies have little if any value except where an extreme deficiency exists. Corn often breaks off at the surface of the ground where potash is a limiting element for its production (Figure 6).

Deficiencies of potash would be expected to occur:

1. Where fertilizers containing large amounts of sulphur have been used for several years.

2. Where harvested peanuts, hay crops, silage, corn including stover, small grains including straw, and other crops, most of which were harvested, have been grown.

FIG. 8.—An intermediate stage of potash deficiency for cotton. (Courtesy South Carolina Agricultural Experiment Station.)
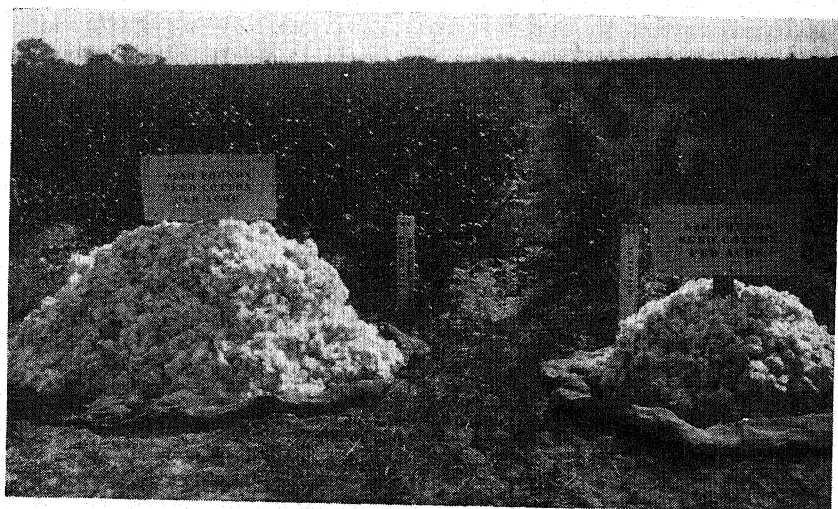
FIG.9.—A late stage of potash deficiency for cotton. (Courtesy South Carolina Agricultural Experiment Station.)

Cotton rust is a nutrient deficiency symptom which is most often caused by a shortage of potash. Where lime is extremely low, deficiency symptoms show up, which probably are not distinguishable from those produced by a shortage of potash. The latter condition has been observed with the use of sulphate of ammonia on a soil which was extremely low in lime. Most cases of cotton rust may be due to potash deficiency. However, the author has not been able to distinguish between deficiency symptoms of potash and lime for cotton at maturity.

Seventeen tests were conducted on 5 farms in Alabama (36) where cotton had previously shown severe rust (Table 13). The fertilizer used was 600 pounds per acre of 6-8-0 with 4, 6, 8, 12, 16, and 20% potash. Potash increased cotton yields and eliminated rust in all 17

Table 13.—The Effect of Different Rates of Potash on the Yield of Cotton Grown on Soils Known to Produce Rusted Cotton[1].

Test No.	Fertilizer Treatment—600 pounds per acre						
	6-8-0	6-8-4	6-8-6	6-8-8	6-8-12	6-8-16	6-8-20
	Yield—pounds of seed cotton per acre						
1	653	750	790	823	847	R895X[2]	823
2	605	799	869	920X	R847	726	484
3	317	590	768	885	995	R1061X	1009
4	663	832	884	901X	R910	859	879
5	711	799	924	953X	R953	789	750
6	799	803	920	997	R1026X	1005	959
7	1157	1291	1426	R1856X	1695	1639	1399
8	904	1377	1552	R1964X	1668	1033	737
9	515	780	844	1074	1157X	R1004	1056
10	477	917	1074	1174X	R1086	1061	1086
11	368	573	694	824	R904X	598	517
12	198	591	821	847X	818	R861	920
13	582	757	957	997X	R957	927	911
14	543	757	957	1045	1213	R1233X	1227
15	623	824	985	1092X	R1045	1106	1072
16	690	945	1039	1079X	R1069	1065	1109
17	630	858	964	1079	1139X	R1152	1146
Average	614	838	969	1089X	R1078	1001	946
Average increase		224	355	475	464	387	332

[1]Tests covered the period 1940 to 1943, inclusive, and were conducted on five farms in three counties in Southeast, Alabama. Each test represents two replications.
[2]R = rate of potash necessary to eliminate cotton rust; X = most profit with potash at 8.5 cents per pound, and seed cotton at 8 cents per pound.

tests. In several of the tests the most profitable percentage of potash was less than that required to eliminate rust. On the average a 6-8-8 was the most profitable fertilizer.

Increasing the amount of potash beyond the amount required to eliminate cotton rust usually reduced the yield, and in some cases the yield produced with an excessive amount of potash was less than if no potash had have been used. The cotton on plots which received excessive amounts of potash was later maturing, and was damaged more by boll weevils, due to the late maturity. It appears to the author that the leaching of other nutrients by the chlorine in the potash fertilizer may have been responsible for the high rates of potash reducing the yield rather than a result produced directly by potash. It appears reasonable that the deficiency may have been magnesium; however, the possibility that the chlorine leached the calcium applied in the fertilizer should not be overlooked.

Soda in nitrate of soda reduced cotton rust; while superphosphate increased cotton rust. The increase in rust where superphosphate was used was attributed to increased growth, which increased the need for potash; however, the effect of the sulphate in superphosphate on the leaching of potash should not be overlooked.

SUMMARY AND CONCLUSIONS

The potash used by the American farmers before the first World War was imported from Europe. At the present time it comes from American mines. The known reserves of easily-mined potash in this country will last about one hundred years at the present rate of consumption, and less time if the yearly consumption is increased. It appears imperative that efforts be made to determine whether unknown reserves of potash exist, or that peace time restrictions be placed on the mining of American potash.

The data reviewed in this chapter show that:

1. The known potash reserves in the United States will last about 100 years at the present rate of consumption.
2. High grade muriate of potash is the cheapest source of potash.
3. Each ton of filler or dolomite used to dilute high grade muriate of potash to make fertilizer of lower potash content increases the cost about $15.00.
4. There is no kainit on the American market. The so-called kainit is made by diluting high grade muriate of potash with sand or dolomite.
5. The table salt contained in manure salts is valuable for the production of many crops.
6. Too much chlorine from muriate of potash reduces the quality of tobacco.

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(13)

Production and Use of Commercial

Nitrogenous Fertilizers

Both crops and ammunition contain nitrogen.

The nitrogenous fertilizers used for crop production are organic materials obtained from plant and animal industries, and nitrogen obtained from the air, coal, and the Chilean nitrate deposit. The nitrogen which is taken from the air is largely cyanamid and synthetic ammonia. The nitrogen which is obtained from coal is recovered as a by-product from gas and coke industries. The statistics (4)[1] on world production of nitrogenous fertilizers are as follows:

Type of production	In thousands of tons by calendar years				
	1900	1913	1924	1929	1934
By-product............	110.0	312.5	352.3	496.6	393.6
Synthetic.............	......	24.2	355.5	1102.1	1331.9
Cyanamid............	......	42.0	120.5	250.7	238.5
Chilean nitrate........	220.0	472.7	412.4	554.8	144.5
Total............	330.0	851.4	1240.7	2404.2	2108.5

The world production of nitrogen increased from 330,000 tons in 1900 to 2,404,200 tons in 1929, and dropped to 2,108,500 tons in 1934. Prior to 1900 the production of nitrogen was limited to Chilean nitrate of soda and by-product nitrogen from the coking industry, and in 1900 Chilean nitrate of soda supplied two-thirds of the total nitrogen. Chilean nitrate of soda production increased from 220,000 tons of nitrogen in 1900 to 554,800 tons in 1929, and in 1934 only 144,500 tons of Chilean nitrate nitrogen was produced. There has not been a marked change in the production of by-product nitrogen since 1913, except for a decrease during the depression. World War I stimulated the de-

[1]Numbers in parenthesis refer to the source of information, page 335.

velopment of synthetic nitrogen fixation processes; World War II doubled the capacity to produce synthetic nitrogen.

No cyanamid or synthetic nitrogen was produced in 1900 (2). The production of synthetic nitrogen was 24,200 tons in 1913; 355,500 tons in 1924; 1,102,100 tons in 1929, and 1,331,900 tons in 1934. The production of synthetic nitrogen is the only type of production which increased during the depression, and the increase is significant in that it indicates a trend in types of production.

The distribution of the capacity to produce nitrogen by countries in 1934, and the production by specified years (4) are reported in Table 1.

Table 1.—CAPACITY AND PRODUCTION OF NITROGEN BY COUNTRIES.

Country	Capacity—1934 percentage of each type					Production in thousands of tons per year			
	Syn-thetic	Cy-ana-mid	By-prod-uct	Chil-ean	Total	1913	1924	1929	1934
Germany...	22.3	3.9	2.7	...	29.0	131.6	470.7	889.9	462.5
Chile.......	...	...	...	13.6	13.6	476.7	413.3	556.0	141.7
United States....	6.7	...	3.9	...	10.6	39.5	129.6	318.9	256.7
Great Britain...	5.3	...	2.4	...	7.7	99.5	108.4	217.7	175.0
France.....	5.4	0.9	1.0	...	7.2	18.9	33.6	103.9	187.5
Japan......	4.3	1.4	0.2	...	5.9	3.9	36.9	90.5	208.0
Belgium....	4.0	0.1	0.5	...	4.7	10.9	13.9	44.2	109.8
Soviet Union....	3.6	0.1	0.3	...	4.0	3.2	0.7	5.3	45.0
Italy.......	2.4	0.4	0.1	...	3.0	6.3	15.8	56.0	98.6
Netherlands	2.4	...	0.2	...	2.6	1.6	7.9	13.5	62.9
Norway....	2.3	0.3	...	...	2.5	22.0	25.0	75.0	65.5
Canada....	0.7	1.5	0.2	...	2.5	.....	......	......	....
Poland.....	1.4	0.8	0.1	...	2.3	.....	......	......	....
All other countries.	2.8	1.2	0.6	...	4.3	29.3	65.6	181.3	158.8
Total....	63.8	10.6	12.2	13.6	100.0	843.5	1,321.4	2,552.2	1,972.0

Germany had almost as much capacity to produce nitrogen as the combined capacity of the United States, Great Britain, and Chile, and the named countries had 61% of the world capacity and 57% of the world production in 1934. It is significant that production in Germany in 1934 was 52%, Chile 25%, United States and Great Britain 80% of the 1929 production. During the same period, the production increased significantly in France, Japan, Belgium, Soviet Union, Italy,

and the Netherlands. Norway experienced a slight reduction in the quantity produced.

The production of nitrogen in the United States has increased rapidly since World War I. The production of by-product nitrogen from coal depends upon the use of coal, and the changes which have taken place probably reflect changes in the production of coke and gas from coal. The United States produced 185,000 tons of by-product nitrogen in 1943 (1). There was no synthetic nitrogen produced in the United States in 1914, and by 1935 there were 176,025 tons of synthetic nitrogen produced, as compared to 116,250 tons from coal. The 1944 synthetic nitrogen capacity of the United States was 1,186,100 tons of nitrogen (1).

Synthetic ammonia is produced by the combination of hydrogen and nitrogen under high pressure in the presence of some substance which promotes the combination. Since 1930 over 50% of the world production of nitrogen has been ammonia made in this manner. The ammonia may be changed into urea, nitrate nitrogen, or it may be used to make ammonium phosphate and ammonium nitrate. It is also used in the ammoniation of superphosphate. There were two large and six small synthetic nitrogen plants in the United States in 1934, and there are a total of about 23 plants at the present time.

Synthetic ammonia is burned over a platinum gauze to produce nitrate nitrogen, which in turn is used in making ammonium nitrate and nitrate of soda.

Nitrate nitrogen may be made directly by combining oxygen and nitrogen by means of an electric arc. The nitrate nitrogen is absorbed in water and later combined with sodium, calcium, or ammonia to form nitrate of soda, calcium nitrate, and ammonium nitrate. The process requires large amounts of electricity and a high investment in equipment, which depreciates rapidly. There are no plants of this type in this country.

The conversion of synthetic ammonia into solid fertilizer materials presents problems which are difficult to handle. Due to its low nitrogen content calcium nitrate is a high-priced source of nitrogen by the time it reaches the farm; due to its characteristic of absorbing water from the air, it is not easily applied.

The low nitrogen content of nitrate of soda causes it to be expensive as a source of nitrogen. The soda in nitrate of soda also increases its cost. Consequently, the amount of nitrate of soda made synthetically may be limited by the amount of soda obtained as a by-product from other industries. Since the soda in nitrate of soda has a value for certain

crops, the relative value of nitrate of soda may be sufficient to justify a price which would permit the production of soda ash especially for this purpose.

The two cheapest sources of nitrogen in solid form which may be made from synthetic ammonia are urea and ammonium nitrate, both of which take water out of the air, which gives them poor handling properties. However, the poor physical properties of ammonium nitrate can be improved (2) by

(a) Converting fine-grained ammonium nitrate crystals into pellets of larger size, or producing coarse-grained ammonium nitrate.

(b) Coating the particles of ammonium nitrate with one-half percent of a mixture of petrolatum, rosin, and parafin, and coating afterwards with 2 to 4% clay.

(c) Bagging and shipping ammonium nitrate at temperatures below 100° F., using moisture-proof bags.

(d) Avoiding long storage periods during summer and fall.

Mixtures of ammonium nitrate and dolomite may be processed with good physical properties; however, they may not be widely used, due
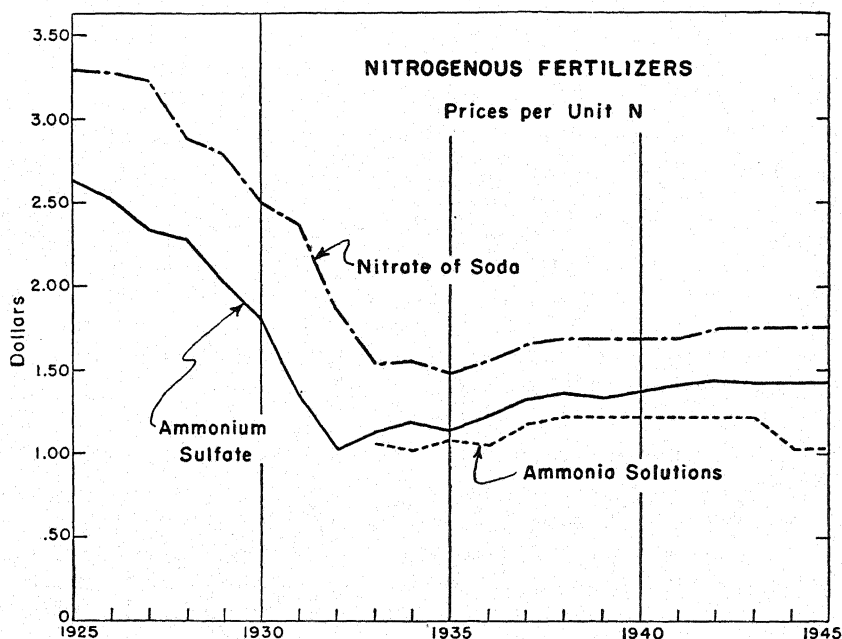
FIG. 1.—Wholesale price of 20 lbs. of nitrogen Baltimore, Maryland. (Courtesy) U.S.D.A.

to their low nitrogen content which results in relatively high cost to the farmer.

Chilean nitrate of soda is leached with water from a low-grade deposit, and the water is evaporated. The high costs involved in the recovery of Chilean nitrate of soda are probably responsible for only 7% of the total 1934 world consumption of nitrogen being Chilean nitrate of soda, while in 1900 67% of the total nitrogen was from this source.

Cyanamid is produced by treating calcium carbide with nitrogen gas at 1000° C. The calcium carbide is made by heating coke and limestone together. The production of cyanamid is handicapped by the high power requirement for making calcium carbide, and the high cost of the original equipment. The United States Government built a cyanamid plant at Muscle Shoals, Alabama, during the first World War, but it was never used and has been partly dismantled. The cyanamid used in this country is produced largely at Niagara Falls, Ontario, Canada.

By-product ammonia nitrogen is recovered in water or sulphuric acid in the production of coke and coal gas. In the United States at the present time over 96% of the ammonia produced in the coke industry is recovered. From each ton of coal 22 pounds of nitrogen may be recovered as a by-product. Eighty to 85% of the by-product ammonia is sold as sulphate of ammonia. In 1934 there were 77 plants recovering nitrogen from coal. The nitrogen obtained from coal is a by-product, and coke and gas will be produced from coal regardless of whether or not the nitrogen is recovered. The actual cost of producing by-product nitrogen is essentially the cost of the recovery of the ammonia. By-product nitrogen usually sells in times of depression as well as in times of prosperity, due to the fact that no charge needs to be made directly to the process for the ammonia. During depressions the production of by-product nitrogen, although reduced, may continue without serious interruption, and the reduction in output of nitrogen may largely take place in synthetic nitrogen plants, where there is a direct cost involved in the production of the ammonia.

It has been suggested that the cost of recovering by-product ammonia is as much as the cost of producing ammonia from nitrogen and hydrogen. If this is correct by-product ammonia may not be recovered in the near future, except under conditions where it can not be released into the air or streams. However, the use of power and coal to produce synthetic ammonia while by-product ammonia is being lost would be a national loss.

Table 2.—Imports and Exports of Nitrogen by the United States.

	1928	1929	1930	1931	1932	1933	1934	1935
	Tons of nitrogen							
Production....	153,436	207,919	207,142	169,138	118,979	155,815	186,860	196,376
Imports......	254,478	226,432	164,147	151,027	101,502	129,720	130,765	136,556
Exports......	25,895	39,019	24,951	32,096	33,902	21,671	36,176	45,356
Apparent consumption	382,019	395,332	346,338	288,069	186,579	263,864	281,449	287,576

In 1935 the United States imported about half as much nitrogen (4) as was produced in this country (Table 2). With the exports averaged in, about three-fourths of the nitrogen consumed was produced in this country.

During the period 1880-1932 there was a marked change in the sources of nitrogen used (3, 4) in mixed fertilizers (Table 3). The nitrogen in mixed fertilizers was 88% from organic sources in 1880, and 18% in 1932. Organic sources of nitrogen include cottonseed meal and animal tankage, which have had a higher value for feeding livestock than for fertilizer during recent years. The use of ammonia and its salts increased from a very low amount in 1880 to 68.6% of the total in 1932. Sulphate of ammonia was the primary source of ammonia nitrogen in 1932. Cyanamid, ammonium nitrate, and urea have supplied up to 11% of the nitrogen since 1920. The nitrate nitrogen which goes into mixed fertilizers is derived primarily from ammonium nitrate.

The tonnage of nitrate of soda sold direct to farmers (3) in the United States in 1939-1940 exceeded that of all other sources of nitrogen (Table 4). In the South the nitrate of soda sold direct to

Table 3.—Changes in Sources of Nitrogen Going into Mixed Fertilizers.

Year	Ammonia and its salts	Nitrates	Cyanamide, urea, etc.	Organic ammoniates	Year	Ammonia and its salts	Nitrates	Cyanamide, urea, etc.	Organic ammoniates
	Percent					Percent			
1880	7.8	3.9	....	88.3	1927	51.0	12.9	9.2	26.9
1890	14.4	7.6	....	78.0	1929	51.3	14.8	11.3	22.6
1900	5.8	23.4	....	70.8	1930	54.7	12.8	7.9	24.6
1910	26.3	18.4	....	55.3	1931	57.4	11.6	7.5	23.5
1920	24.6	29.5	8.6	37.3	1932	56.4	14.0	11.3	18.3
1925	38.1	21.9	9.0	31.0	1939–1940	68.6[1]	9.0	9.0	13.1

[1]Including nitrogen solutions.

Table 4.—Tonnage of Different Sources of Nitrogen.

Section	Tons of nitrogenous fertilizer materials applied directly in 1939-1940			
	Nitrate of soda and nitrate of potash	Sulphate of ammonia	Other chemical nitrogen[1]	Natural organic nitrogen[2]
North and Middle Atlantic....	27,600	6,300	9,400	36,300
Middle West................	4,600	13,100	2,600	12,300
South.....................	588,300	80,500	90,200	181,100
West......................	15,000	63,500	33,900	13,200
Total.................	635,500	163,400	136,100	242,900

[1]Cyanamid, calcium nitrate, urea, etc., not including those that supply more than 1 plant food, e.g., ammonium phosphate, potassium nitrate, etc.
[2]Dried manures, tankage, cottonseed meal, etc.

farmers was almost twice as much as all other sources of nitrogen combined.

The consumption of nitrogen in mixed fertilizers and that applied directly (3) is shown by the data in Table 5. The use of nitrogen applied directly increased from 35% of the total in 1925-26 to 46% of the total in 1940-41. The nitrogenous fertilizer materials listed as applied

Table 5.—The Consumption of Nitrogen in Mixed Fertilizers and in Materials in the United States.

Season	Quantity			Percent of total	
	Total consumption	Consumed in mixtures	Applied directly	Consumed in mixtures	Applied directly
	Tons	Tons	Tons	Percent	Percent
1925/26	241,000	156,000	85,000	64.7	35.3
1926/27	225,000	150,000	75,000	66.7	33.3
1927/28	292,000	185,000	107,000	63.4	36.6
1928/29	305,000	198,000	107,000	64.9	35.1
1929/30	316,000	206,000	110,000	65.2	34.8
1930/31	262,000	162,000	100,000	61.8	38.2
1931/32	182,000	112,000	70,000	61.5	38.5
1932/33	228,000	124,000	104,000	54.4	45.6
1933/34	231,000	139,000	92,000	60.2	39.8
1934/35	287,000	152,000	135,000	53.0	47.0
1935/36	317,000	165,000	152,000	52.1	47.9
1936/37	393,300	214,000	179,300	54.4	45.6
1937/38	364,800	190,000	174,800	52.1	47.9
1938/39	366,000	193,500	172,500	52.9	47.1
1939/40	380,800	204,000	176,800	53.6	46.4
1940/41	397,300	214,200	183,100	53.9	46.1

directly were used in home-mixing, side-dressing, and as materials before planting.

It appears that more than 50% of the nitrogen may be bought as materials with the recent favorable relative cost of fertilizer materials as compared to mixed fertilizers. If the difference between the cost of home-mixed and factory-mixed fertilizers increases, more materials and less mixed fertilizer may be bought; if the difference between the cost of these fertilizers decreases, less materials will be bought. It appears that the mixed fertilizer industry might get a larger share of the fertilizer business by the production of higher analysis fertilizers, in which the plant nutrient cost is less.
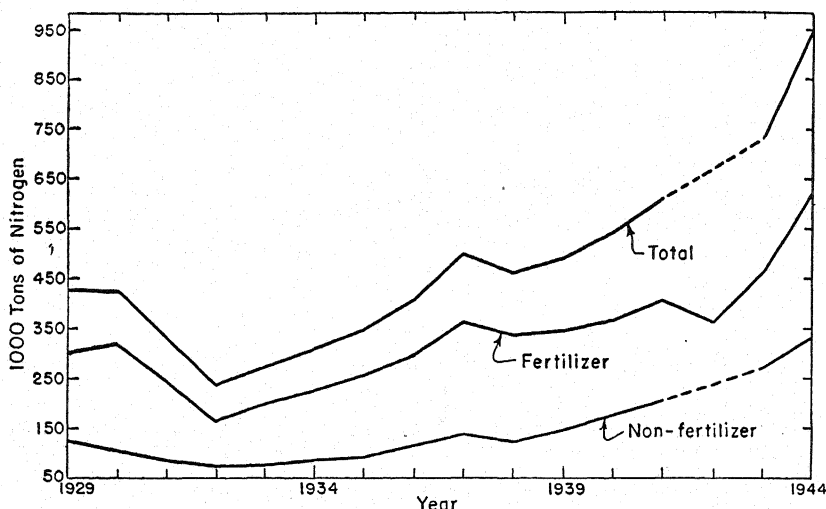
FIG. 2.—Domestic Consumption of Chemical Nitrogen for Fertilizer and non-fertilizer purposes. (Courtesy U.S.D.A.)

The air is about 78% nitrogen. Over each square mile of surface there is sufficient nitrogen to make approximately 150 million tons of nitrate of soda (1). The nitrogen in the air is not combined with any other element; consequently, crop plants can not use it. Certain bacteria which live in nodules on the roots of legumes and on organic matter in the soil can use the nitrogen in the air. The nitrogen in the air has to be combined with other elements before crop plants can use it.

The cost of building and operating manufacturing plants (4) to take one pound of nitrogen out of the air and to combine it with other elements so that it may be used by crops has been estimated as follows:

Product	Cost per pound of nitrogen
Ammonia.....................	3.3 to 4.4 cents
Cyanamid...................	7.1 cents
Nitrate.....................	12.1 cents

To the above costs, the profits and distribution costs must be added to arrive at the price paid by farmers. Since the retail price of nitrogen in materials is normally from 8 to 12 cents per pound, the above data suggest that future development will be primary in plants which produce ammonia nitrogen. The cost of converting one pound of ammonia nitrogen into nitrate nitrogen has been unofficially estimated to be about 1 cent per pound. The cyanamid plants which have been built may continue to operate, but new cyanamid plants will probably not be built. The direct nitrate producing plants may cease production if they have not already done so.

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(14)

Mixed Fertilizers

The first fertilizer used to any extent was guano. Guano is bird manure which contains approximately 12% nitrogen, 10% phosphoric acid, and 3% potash. Guano was a good fertilizer, and fertilizer mixers set out to take the available fertilizer materials and make an artificial guano. In many sections, mixed fertilizer is referred to as guano at the present time.

The popularity of mixed fertilizers containing all three elements may be due to the fact that all three elements were present in guano. In the United States a large proportion of the nitrogen, phosphorus, and potash is bought as mixed fertilizers. In Europe the tendency is to buy fertilizer materials containing the desired element.

EACH DOT REPRESENTS 5,000 TONS

From Fertilizer Review
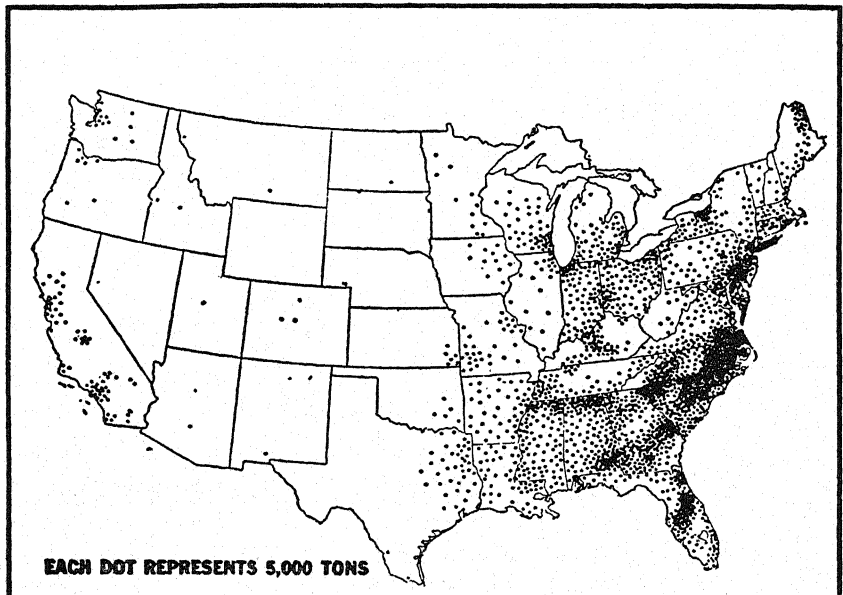
FIG. 1.—Distribution of the fertilizer consumed in the United States in 1943 (5).

The term complete fertilizer is applied to fertilizers containing nitrogen, phosphorus, and potash. The term may be misleading in that it carries the meaning that these three elements are supplied in the ratio needed for the most economical crop production. For any particular soil a so-called complete fertilizer may supply nitrogen, phosphorus, and potash where one or more of these elements are not needed. or it may supply an insufficient quantity of one or more of these elements. Unless the three element fertilizers contain nitrogen, phosphorus, and potash in the proportion needed for the most economical production of the crop in question, the term complete fertilizer may be an overstatement.

Incomplete fertilizers are referred to as fertilizers which supply only two of the elements, nitrogen, phosphorus, and potash. This term may likewise be misleading in that it may meet the fertilizer requirement of the crop and soil in question.

"Balanced fertilizer" is a term applied to mixed fertilizers, which implies that the fertilizer supplies the three elements, nitrogen, phosphorus, and potash in the ratio needed by the crops on the particular soil. If the data on which the particular fertilizer ratio was selected were sufficiently reliable, the fertilizer is balanced for the particular crop, soil, and weather conditions, and it might not be balanced if these factors were changed. Obtaining balanced fertilizers for the different soils on each farm is an ideal toward which all interested are working. The success to date may not warrant the use of the term "balanced fertilizer".

A fertilizer formula is a list of the kinds and amounts of fertilizer materials required for mixing together for any purpose. The following fertilizer formulas are illustrative:

Formula for one ton of 6-8-4 fertilizer:

	Pounds
Nitrate of soda	750
Superphosphate	1000
Muriate of potash	160
Filler	90
Total	2000

Formula for four acres of cotton

	Pounds
Nitrate of soda	750
Superphosphate	1000
Muriate of potash	160
Total	1910

Per cent denotes the pounds of plant nutrient or other constituent in each 100 pounds of fertilizer.

A unit of plant nutrient is 20 pounds of nitrogen, phosphate, or potash.

Fertilizer analysis refers to the per cent of (a) total nitrogen, (b) available phosphoric acid, and (c) water soluble potash in the fertilizer.

Fertilizer ratio refers to the relative amount of total nitrogen, available phosphoric acid, and water soluble potash. The following fertilizer analyses have a 1-2-1 ratio of total nitrogen, available phosphoric acid, and water-soluble potash: 4-8-4, 5-10-5, and 6-12-6. The ratios for 4-8-4, 4-8-8, 8-8-4, and 7-7-7 are 1-2-1, 1-2-2, 2-2-1, and 1-1-1 respectively. A fertilizer ratio does not indicate the amount of the different elements in the fertilizer.

The fertilizing elements in fertilizers of one ratio and different analysis are of equal value when and only when the sources of nitrogen, phosphorus, potash, and other constituents are identical. Evidently, this condition would occur only where different fertilizer analyses are produced by varying the amount of inert filler like sand in the mixture. As an illustration, the nitrogen, phosphorus, and potash in 2 tons of 6-12-6 fertilizer are equal in crop producing power to that in 3 tons of 4-8-4 provided the fertilizer materials come from the same source. The 3 tons of 4-8-4 would have one ton more filler. However, if the nitrogen, phosphorus, and potash in 4-8-4 and 6-12-6 come from different sources, there is little reason to expect 2 tons of 6-12-6 and three tons of 4-8-4 fertilizer to have the same fertilizing value.

Filler is inert material used in fertilizers to add weight. In the early days of the fertilizer industry many fertilizer materials contained a low percentage of nitrogen, phosphate, and potash. The fertilizer materials were mixed together to give low analysis fertilizers. With the introduction of fertilizer materials containing a high percentage of nitrogen, phosphate, and potash to make mixed fertilizers of low analysis, it became necessary to add some inert material of low cost to increase the weight of the mixture to one ton without increasing the amount of nitrogen, phosphate, and potash. The inert material is called filler.

The filler commonly used in mixed fertilizer is sand. However, rock phosphate, peat and muck are sometimes used. Some reference has been made to the use of dolomite as filler in recent years. Since the value of the fertilizer is influenced by the amount of calcium and magnesium it contains, it seems that dolomite should not be considered

filler. The use of dolomite reduces the amount of inert filler necessary to add to the mixture.

The fertilizers used in the United States by crops and regions are reported in Tables 1, 2, and 3 (5, 8).[1] The South Atlantic and South Central States used 64% of all of the fertilizers in 1943. About 25% of the fertilizers were used in the Middle Atlantic and East North Central States in 1943.

Corn receives more fertilizer than any other crop, followed by cotton, fruits and vegetables, wheat, and hay and pasture crops. The very rapid increase in the use of fertilizers on hay and pasture crops suggests that these crops may receive more fertilizer than any other crop in the near future. However, it should be pointed out that these

Table 1.—FERTILIZER CONSUMPTION BY REGIONS, 1910-1943.

Region	1910		1920		1930		1943	
	1,000 tons	*Per-cent*	*1,000 tons*	*Per-cent*	*1,000 tons*	*Per-cent*	*1,000 tons*	*Per-cent*
New England.....	208	3.8	351	4.9	372	4.5	454	3.9
Middle Atlantic....	853	15.6	1,017	14.2	1,086	13.2	1,453	12.6
E. North Central..	339	6.2	672	9.4	788	9.6	1,491	12.9
W. North Central..	34	0.6	115	1.6	110	1.3	302	2.6
South Atlantic.....	3,146	57.7	3,999	55.7	3,857	47.0	4,827	41.8
South Central.....	827	15.2	942	13.1	1,812	22.1	2,552	22.1
West............	45	.8	80	1.1	187	2.3	458	4.0
Total tons....	5,452	100.0	7,176	100.0	8,212	100.0	11,537	100.0

Table 2.—FERTILIZER CONSUMPTION BY CROPS.[2]

Crop	Fertilizer tonnage per cent of total		
	1927	*1938*	*1942*
Cotton..........................	31.4	20.5	15.3
Corn...........................	22.5	22.3	22.6
Potatoes........................	10.3	7.6	6.7
Wheat..........................	10.2	10.1	7.7
Fruit and vegetables..............	8.9	14.1	15.9
Tobacco........................	7.0	6.9	5.2
Hay and pasture.................	....	3.3	14.1
Other crops.....................	9.7	15.2	12.5
Total tonnage................	6,843,000	7,490,000	8,779,000

[1]Includes the tonnage distributed by governmental agencies in 1938 and 1942, most of which was used on hay or pastures.

[2]Numbers in parenthesis refer to the source of information, page 357.

crops have received a large part of the fertilizer distributed by the government, and that they might receive less if the government should discontinue distribution.

Table 3.—FERTILIZERS USED BY STATES,[1] 1935-1944 (8).

State and division	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944[2]
	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons
Maine.........	125	130	142	139	139	147	165	153	217	221
New Hampshire	16	17	14	13	14	19	30	28	28	21
Vermont......	15	16	25	25	35	29	75	42	31	38
Massachusetts .	63	64	74	69	66	69	80	82	87	92
Rhode Island...	10	10	11	12	11	12	14	14	15	15
Connecticut....	51	53	67	57	60	63	70	71	76	74
New York.....	285	315	350	333	319	398	470	466	503	479
New Jersey....	150	161	184	172	176	184	184	212	223	253
Pennsylvania...	295	318	370	359	374	365	392	384	414	488
No. Atlantic.	1,010	1,084	1,237	1,179	1,194	1,286	1,480	1,452	1,594	1,681
Ohio..........	306	337	362	325	346	366	410	462	528	560
Indiana.......	190	246	227	221	202	258	281	357	396	479
Illinois........	24	31	36	36	41	50	70	84	111	196
Michigan......	111	126	145	133	145	166	190	260	264	297
Wisconsin.....	28	32	43	46	43	71	89	195	179	217
Minnesota.....	11	10	12	14	13	19	32	48	54	77
Iowa..........	5	6	9	12	13	16	23	46	60	76
Missouri.......	59	94	83	71	68	93	97	120	150	180
Kansas........	7	11	15	18	14	18	22	27	32	46
Other States...	1	1	1	3	4	4	4	5	6	6
No. Central..	742	894	933	879	889	1,061	1,218	1,604	1,780	2,134
Delaware......	38	39	44	36	36	35	35	38	45	45
Maryland.....	165	165	186	166	165	161	173	185	209	216
Dist. of Col....	1	1	2	2	2	2	2	2	2	2
Virginia.......	379	392	446	412	438	427	458	514	535	563
West Virginia..	55	55	40	42	54	59	76	91	69	70
North Carolina.	1,001	1,043	1,239	1,107	1,221	1,091	1,176	1,278	1,444	1,407
South Carolina.	614	627	771	661	679	686	735	704	895	811
Georgia.......	618	687	868	769	691	783	834	920	1,146	1,081
Florida[3].......	418	513	579	556	498	516	598	594	723	830
So. Atlantic..	3,289	3,522	4,175	3,751	3,784	3,760	4,087	4,326	5,068	5,025
Kentucky.....	73	91	137	144	159	273	301	332	262	309
Tennessee.....	96	128	154	143	154	212	236	279	302	343
Alabama......	422	470	632	532	568	617	615	626	829	823
Mississippi.....	214	241	327	327	320	323	377	399	509	456
Arkansas......	40	49	69	68	79	116	141	165	203	172
Louisiana......	93	117	158	149	161	158	186	182	220	233
Oklahoma.....	7	6	7	8	8	8	13	15	25	24
Texas.........	62	66	90	84	96	119	147	148	202	225
So. Central..	1,007	1,168	1,574	1,455	1,545	1,826	2,016	2,146	2,552	2,585
Washington....	21	23	28	27	25	42	46	50	54	56
Oregon........	13	14	19	18	20	25	29	25	39	42
California.....	179	207	233	208	219	217	265	302	322	450
Other States...	15	19	27	31	31	32	42	44	54	99
Western.....	228	263	307	284	295	316	382	421	469	647
United States	6,276	6,931	8,226	7,548	7,707	8,249	9,183	9,949	11,463	12,072

[1]Includes concentrated superphosphate distributed by Agricultural Adjustment Agency and the Tennessee Valley Authority. This was excluded in the earlier publications of this table.

[2]Preliminary.

[3]Florida data for 1939-43 have been revised by eliminating the tonnage of raw phosphate rock and liming materials.

Bureau of Agricultural Economics. Compiled from reports of the National Fertilizer Association.

The fertilizers used as materials and as mixed fertilizers in 1944 are reported in Table 4. About one-fourth of the superphosphate and

Table 4.—FERTILIZERS USED AS MATERIALS AND IN MIXED FERTILIZERS (8). IN THE UNITED STATES AND TERRITORIES, YEAR ENDED JUNE 30, 1944 (PRELIMINARY).

Material	In continental United States			In non-contiguous Territories	Grand total
	Mixed	As such	Total		
	Tons	Tons	Tons	Tons	Tons
Normal superphosphate[1]	4,292,000	1,578,000	5,870,000	59,000	5,929,000
Nitrate of soda	12,000	824,000	836,000	7,000	843,000
Muriate of potash	758,000	38,000	796,000	35,000	831,000
Sulphate of ammonia	578,000	137,000	715,000	115,000	830,000
Ammonia and solutions	332,000	15,000	347,000	3,500	350,500
Dolomite and limestone[2]	320,000	....	320,000	....	320,000
Ammonium nitrate[3]	90,000	162,000	252,000	31,000	283,000
Manure salts	214,000	26,000	240,000	....	240,000
Rock phosphate	28,000	196,290	224,290	10	224,300
Land plaster[4]	80,000	133,000	213,000	....	213,000
Double superphosphate[5]	60,000	79,500	139,500	10	139,510
Sulfate of potash and of potash-magnesia	114,600	7,200	121,800	4,200	126,000
Process tankage	108,200	800	109,000	....	109,000
Tobacco stems	97,000	1,000	98,000	....	98,000
Basic slag	....	91,000	91,000	....	91,000
Sewage sludge, activated	71,000	20,000	91,000	....	91,000
Wet-mixed base goods	91,000	....	91,000	....	91,000
Cyanamid	9,000	81,000	90,000	....	90,000
Castor pomace	82,000	5,000	87,000	....	87,000
Dried animal manures	20,000	42,000	62,000	....	62,000
Peat	16,500	39,500	56,000	....	56,000
Ammonium phosphate, 16-20	20,000	28,000	48,000	7,000	55,000
Sewage sludge, other	20,000	30,000	50,000	....	50,000
Cottonseed meal[6]	35,000	15,000	50,000	....	50,000
Peanut-hull meal	30,000	....	30,000	....	30,000
Ammonium phosphate, 11-48	10,200	5,400	15,600	6,400	22,000
Nitrate of soda-potash	2,000	12,500	14,500	4,800	19,300
Garbage tankage	13,800	200	14,000	....	14,000
Manganese sulfate	13,000	1,000	14,000	....	14,000
Cocoa shells	12,000	....	12,000	....	12,000
Bone meal	1,100	9,900	11,000	....	11,000
Dried fish scrap	5,000	2,700	7,700	....	7,700
Tung meal	3,000	2,000	5,000	....	5,000

[1]Grades containing 18 to 22 percent available P_2O_5. Includes 673,074 tons distributed by AAA.
[2]Used as fertilizer filler. In addition, 20,000,000 tons were consumed in agriculture as such.
[3]Includes 9,453 tons used in TVA demonstrations.
[4]As reported by the fertilizer industry. About 200,000 tons more were sold for use in agriculture by other industries.
[5]In addition, about 47,000 tons were used in converting run-of-pile superphosphate into 20 percent material. 30,926 tons, used in TVA test demonstrations, are included.
[6]Approximately 41,580 tons additional were used as fertilizer on cotton farms.

Table 4.—CONTINUED.

Material	In continental United States			In non-contiguous Territories	Grand total
	Mixed	As such	Total		
	Tons	Tons	Tons	Tons	Tons
Guanos................	2,000	200	2,200	....	2,200
Acidulated fish........	2,000	....	2,000	....	2,000
Miscellaneous chemical nitrogen[7]..........	21,800	47,500	69,300	100	·69,400
Miscellaneous organics[8].	7,000	7,200	14,200	5,100	19,300
Miscellaneous phosphates[9].............	5,000	5,500	10,500	....	10,500
Miscellaneous potash materials[10]..........	10,000	6,300	16,300	....	16,300
Miscellaneous materials[11].............	6,000	19,600	25,600	....	25,600
Sand and other filler...	881,000	....	881,000	4,200	885,200
Total............	8,473,200	3,669,290	12,142,490	282,320	12,424,810

[7]Cal-nitro, ANL, Uramon, etc.
[8]Hoof and horn meal, dried blood, various seed meals, animal tankage, etc.
[9]Ammoniated superphosphate, basic lime phosphate, base goods, calcined phosphate rock, phosphoric acid, precipitated bone and spent bone black.
[10]Cement-mill dust, wood ashes, cotton-hull ashes, etc.
[11]Copper sulfate, zinc sulfate, borax, magnesium oxide, sulfur, etc.

Bureau of Plant Industry, Soils, and Agricultural Engineering.
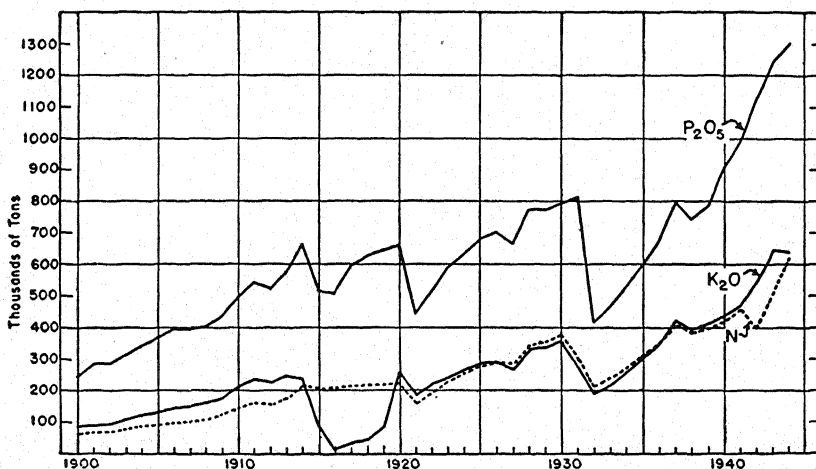
FIG. 2.—Consumption of nitrogen (N) phosphate (P_2O_5), and potash (K_2O) as commercial fertilizer in the United States during the period of 1900–44. (Courtesy U.S.D.A.)

almost 60% of the triple superphosphate were used as materials for direct application. Almost all of the nitrate of soda, cyanamid, and all of the basic slag were used for direct application.

The amount of money spent for fertilizer is largely determined by the previous year's income. The average percentage of the previous year's cash income spent for fertilizers from 1935 to 1939 (4) by regions was:

New England....................................... 4.9%
Middle Atlantic.................................... 4.2%
South Atlantic.....................................13.0%
East North Central................................ 1.5%
West North Central................................ 0.2%
South Central..................................... 2.6%
Western... 0.9%
United States..................................... 2.7%

On the basis of the above data the use of fertilizers can be predicted for any year with a high degree of accuracy.

The plant nutrient content of mixed fertilizers changed radically during the period 1880 to 1940 (6, 10). The average fertilizer analysis was 2.3-8.9-2.2 in 1880, and 3.6-9.5-6.2 in 1939-40, and 3.20-9.90-7.20 during the war year 1943. The average phosphoric acid content of mixed fertilizers has varied from 9.1 to 9.9%; the average nitrogen content has usually increased, and at the present time it is about 30 per cent
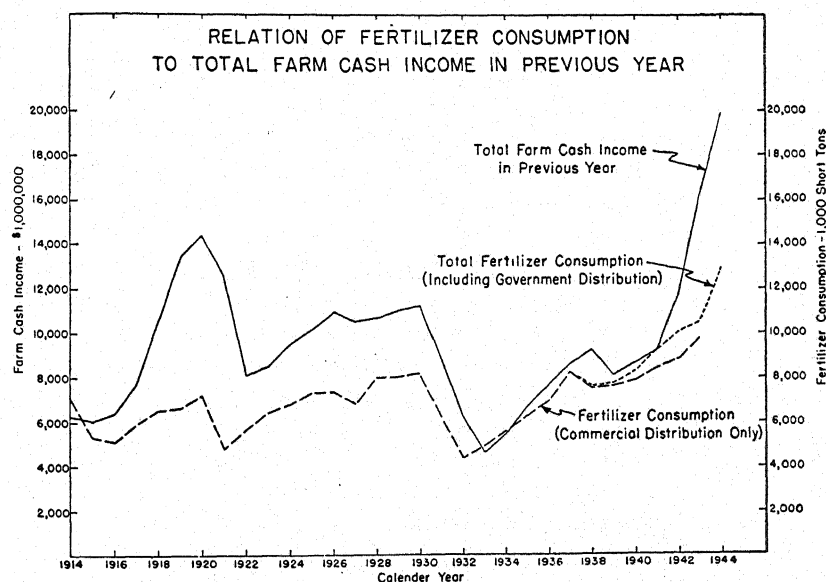
FIG. 3.—Farmer's expenditure for fertilizer compared with farm cash income. (Courtesy U.S.D.A.)

higher than in 1880; and the potash content has increased from 2.2 to 7.2% during this period. The increase in the content of nitrogen and potash in mixed fertilizers is probably due to increased supplies and decreased cost. The probability is that the nitrogen content of mixed fertilizers will continue to increase, or more nitrogen will be used as materials, and that the potash content will increase, particularly in those areas where large acreages are devoted to hay crops.

The total plant-nutrient content of mixed fertilizer increased from 13.4% in 1880 to 20.3% in 1943.

Table 5.—The Average Plant Nutrient Content of Mixed Fertilizers Used in the United States (11).

| Year | Percentage of nutrient | | | |
	Nitrogen	Phosphorus	Potash	Total
1880..........	2.4	9.1	2.0	13.5
1900..........	2.0	9.4	2.5	13.9
1920..........	2.3	9.2	2.4	13.9
1930..........	3.1	9.8	5.0	17.9
1935..........	3.5	9.3	5.5	18.3
1940..........	3.8	9.6	6.4	19.7
1943..........	3.2	9.9	7.2	20.3

The materials going into mixed fertilizers have changed constantly. The formulas in Table 6 are representative of the sources of nitrogen, phosphorus, and potash going into mixed fertilizers (6) at different dates. The phosphoric acid content of the superphosphate going into mixed fertilizers was 12.5% in 1880, 16% in 1910, and 19% in 1937. Concurrently with the increase in the phosphoric acid content of superphosphate, there was probably a reduction in the calcium sulphate content.

The nitrogen in mixed fertilizers (6) was derived 90% from fish scrap and 10% from nitrate of soda in 1880. In 1910 equal amounts of nitrogen came from sulphate of ammonia, nitrate of soda, and cottonseed meal. In 1937 12½% of the nitrogen was derived from nitrate of soda, tankage 15%, and ammonia, sulphate of ammonia and urea 72½%. During World War II no nitrate of soda was used in mixed fertilizers. Dolomite has come into use to offset the acidity produced by the acid-forming nitrogenous fertilizers, the desirability of which is questioned (Chapter 11).

At the beginning of the mixed fertilizer industry, organic materials supplied most of the nitrogen, but at the present time they supply

only a small percentage of it. The substitution of inorganic sources of nitrogen for the organic sources is a distinct advantage on most soils (Chapter 1). The reduction of the relative amount of nitrate of soda in mixed fertilizers since 1910 has reduced their value for many crops.

The potash content of mixed fertilizers (6) was supplied largely by kainit (12½% potash) in 1880, manure salts (20% potash) in 1910, and muriate of potash (62% potash) in 1937. The impurity in kainit

Table 6.—FORMULAS OF MIXED FERTILIZERS FROM 1880 TO 1937.

Period and formula	Pounds per ton	Period and formula	Pounds per ton
1880 (2-9-2):		1937 (4-9-5):	
Superphosphate, 12.5% phosphate..............	1,053	Superphosphate, 19% phosphate.............	947
Fish scrap, 6% nitrogen 8% phosphate..........	600	Ammonia, 2.3% of super-phosphate.............	21
Nitrate of soda, 15.5% nitrogen..............	27	Urea, 46.6% nitrogen......	18
Kainit, 12.5% potash......	320	Sulphate of ammonia, 20.5% nitrogen.........	166
		Nitrate of soda, 16% nitrogen...............	63
Total................	2,000	Tankage, 7% nitrogen....	170
		Potassium chloride, 60% potash................	166
1910 (3-9-3):		Dolomite.................	224
Superphosphate, 16% phosphate.............	1,125	Filler...................	225
Sulphate of ammonia, 20% nitrogen...............	100		
Nitrate of soda, 15.5% nitrogen...............	130	Total.............	2,000
Cottonseed meal, 7% nitrogen...............	285		
Manure salts, 20% potash..	300		
Filler...................	60		
Total.............	2,000		

and manure salts is largely sodium chloride. Sodium chloride has crop producing value for many crops on many soils, and the reduction of the sodium chloride content of mixed fertilizers has reduced their value on those soils on which crops respond to table salt.

Dry base goods is made by mixing superphosphate and sulphate of ammonia with or without potash and other fertilizer materials. The monocalcium phosphate in superphosphate and sulphate of ammonia react, and calcium sulphate and ammonium phosphate are formed. The calcium sulphate takes up water, and in the process the fertilizer becomes hard. These reactions take the free moisture out of the mixture, and it becomes dry. Theoretically, the reaction will go to

completion when more than 200 pounds of sulphate of ammonia is mixed with one ton of superphosphate. These changes are referred to as curing.

After the base goods has been cured and ground, other materials are added to make the desired analysis fertilizer. If all of the materials were mixed together, bagged, and shipped before curing, the fertilizer would arrive at the farm in a hard, lumpy condition.

Wet base goods is made by mixing low grade organic nitrogenous materials like garbage tankage with rock phosphate before treating it with sulphuric acid to make superphosphate. The sulphuric acid converts part of the nitrogen into a more available form.

Ammoniation of superphosphate has come into use since the production of synthetic ammonia began. Ammonia reacts with superphosphate forming ammonium phosphate, sulphate of ammonia, and dicalcium phosphate, and less available tricalcium phosphate and new rock phosphate. Even though superphosphate will take up 6.5 to 7.5% nitrogen as ammonia, the upper limit in practice probably should be only enough to neutralize the free phosphoric acid.

An excess of sulphuric acid is often added in the manufacture of superphosphate to speed up the process. The excess sulphuric acid reacts with monocalcium phosphate forming calcium sulphate and free phosphoric acid. The free phosphoric acid gives superphosphate poor physical properties and rots the fertilizer bags. The first reaction upon adding ammonia to superphosphate is the conversion of the free phosphoric acid into ammonium phosphate. This change gives superphosphate good physical conditions. Dolomite may be used to neutralize the free phosphoric acid where superphosphate is sold as such.

Ammonia is shipped in tank cars in solution with nitrate of soda, urea, or ammonium nitrate. Ammonia can be shipped alone in water or as compressed ammonia gas. However, the ammonia exerts less pressure in solution with the above fertilizers than when shipped in solution or compressed by itself. Due to the high nitrogen content of nitrogen solutions, the cost of transportation of nitrogen in this form is low.

At the present time, superphosphate contains 19% phosphoric acid; potash materials contain 62% potash; nitrogen materials contain up to 82% nitrogen, and as a result high analysis fertilizers may be made. The single strength fertilizer (Table 7) contains 1,358 pounds of materials which supply nitrogen, phosphorus, and potash (6). It is evident that 50% more plant nutrients could be put into a ton of the single strength mixture by omitting the filler and dolomite. The double strength

mixture should be cheaper and probably as efficient as the single strength fertilizer, as compared to the low analysis fertilizer, the high analysis fertilizer has no gypsum from superphosphate (see Chapter 3).

The first mixed fertilizers were basic; at the present they are acid-forming unless dolomite is used to counteract the acidity (6). The first mixed fertilizers were basic because the nitrogen was supplied by nitrate of soda and fish scrap. Sulphate of ammonia, the most acid source of nitrogen commonly used, increased in quantity, and in 1907 mixed fertilizers were neutral; and in 1932 they needed 149 pounds of calcium carbonate per ton to neutralize the acidity.

Table 7.—FORMULAS OF SINGLE AND DOUBLE STRENGTH FERTILIZERS.

Fertilizer material	Single strength mixture (4-8-4)	Double strength mixture (8-16-8)
	Pounds	Pounds
Superphosphate	867	...
Triple superphosphate	...	666
Ammonia	24	48
Urea	34	68
Sulphate of ammonia	122	244
Nitrate of soda	63	126
Tankage	115	230
Muriate of potash	133	266
Dolomite	176	352
Filler (sand)	466	...
Total	2,000	2,000

Dolomite is superior to calcium limestone for use in mixed fertilizers because it is less soluble, and less loss of ammonia and reversion of phosphorus takes place. The superiority of dolomite to calcium lime for neutralizing acid fertilizers may also be attributed to the magnesium supplied by the dolomite. Magnesium deficiencies are produced where fertilizers are used which contain high amounts of sulphur, due to the high solubility of magnesium sulphate (epsom salts). The 4-8-4 fertilizer above containing dolomite could be increased to a 5-10-5 fertilizer by reducing the filler and increasing the fertilizing materials in proportion. By substituting triple superphosphate for regular superphosphate and doubling the other materials, the fertilizer analysis can be increased to an 8-16-8.

In substituting triple superphosphate for regular superphosphate, the only change is the omission of the calcium sulphate which was in

the superphosphate. The calcium sulphate supplies sulphur and calcium to plants, and it has no effect on the acidity of the soil. The sulphur supplied in the sulphate of ammonia, and the calcium and magnesium supplied by the dolomite may make the calcium sulphate in the regular superphosphate unnecessary. Apparently it is possible to make an 8-16-8 fertilizer with the same crop-producing value as twice the amount of 4-8-4 fertilizer may have.
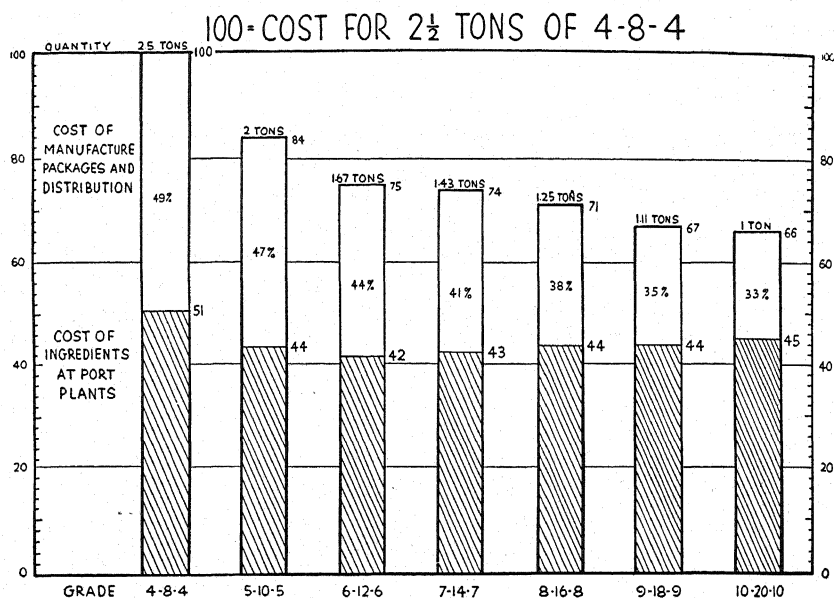
FIG. 4.—The relative cost of low and high analysis fertilizers. (Courtesy M. H. Lockwood, Eastern States Exchange.)

The relative cost of low and high analysis mixed fertilizers is illustrated in Fig. 2. The fertilizers illustrated have a 1-2-1 ratio, and the analysis varies from 4-8-4 to 10-20-10. It is evident that the cost of the materials which go into mixed fertilizers vary only slightly. The savings which may be made from high analysis fertilizers are due largely to reduction in cost of mixing, bags, and distribution. As is pointed out in the following chapter, the profit made from a given investment in high analysis fertilizer instead of low analysis fertilizer is much greater than the savings in buying.

The savings in the use of high analysis fertilizers can be calculated from any fertilizer price list. When there is a reduction of one ton in total tonnage of fertilizer through the use of higher analysis fertilizers,

a saving of about $10.00 to the farmer is obtained, which is the approxi-
mate cost of getting one ton of fertilizer from the mixing plant to the
farm. The cost of getting one ton of fertilizer to the farm may be
calculated from the following price list:

	Analysis	*Cost per ton*
4-8-4		$26.00
6-8-4		30.00
4-8-8		28.80
4-12-4		29.00
6-12-6		34.40

Comparing 6-8-4 at $30.00, and
　　　　　4-8-4 at $26.00
　　　　　　―――――――――
　　　　　2-0-0　　$4.00

A difference of 2% nitrogen in a ton cost $4.00, or $2.00 for 1% nitrogen
in a ton.

Comparing 4-8-8 at $28.80, and
　　　　　4-8-4 at　26.00
　　　　　　―――――――――
　　　　　0-0-4　　$2.80

A difference of 4% potash in a ton cost $2.80, or $0.70 for 1% potash
in a ton.

Comparing 4-12-4 at $29.00, and
　　　　　4-8-4　at　26.00
　　　　　　―――――――――
　　　　　0-4-0　　$3.00

A difference of 4% phosphate in a ton cost $3.00, or $0.75 for 1%
phosphate in a ton. Applying the costs of nitrogen, phosphate, and
potash to a ton of 4-8-4 fertilizer, the following data are obtained:

4% nitrogen in a ton, 4x$2.00　=　　$8.00
8% phosphate in a ton, 8x$0.75　=　　6.00
4% phosphate in a ton, 4x$0.70　=　　2.80
　　　　　　　　　　　　　　　　　―――――
Total cost of fertilizer materials　=$16.80.

Subtracting $16.80 from $26.00 gives $9.20 as the cost of getting one
ton of fertilizer to the farm. The cost of getting a ton of fertilizer to
the farm includes bags, tags, labor, overhead, profit, freight, dealer's
compensation, etc. The above prices show that 2 tons of 6-12-6 should
be bought for $9.20 less than 3 tons of 4-8-4, and the same amount
of nitrogen, phosphate, and potash would be obtained in both cases.

**The quality of the phosphate in high analysis mixed fertilizers may
be higher, due to the fact that less ammonia can be used in the
ammoniation of superphosphate in the high analysis fertilizers with**

the present method for determining available phosphorus in fertilizers (See pages 286 and 296). It was pointed out in Chapter 11 that the use of more than 2% ammonia in superphosphate reduces its value. From the standpoint of the quality of the phosphorus, high analysis fertilizers may, therefore, be more efficient than low analysis fertilizers.

An advantage of low analysis fertilizers to the farmer is that the present fertilizer distributing machinery can be more easily regulated to distribute small amounts of plant nutrients from low analysis than from high analysis fertilizers.

The drilling properties of fertilizers have been observed to vary from morning to night, and as a result the fertilizer distributor has to be regulated continuously. In the early morning when the air is damp, some fertilizers take up moisture from the air and flow out of the distributor slowly. If the distributor is regulated to give the desired amount of fertilizer early in the morning, it may put out too much when the temperature gets higher and the fertilizer flows more freely.

Certain fertilizer materials take water out of the air readily, and some may take up enough water to go into solution; while others do not take any water out of the air. Calcium nitrate, ammonium nitrate, calnitro, and urea absorb water out of the air and become wet and sticky, and they may take up enough water to go into solution and run out of ordinary bags.

When fertilizers take up moisture when the air is damp and lose it when it is dry, crystals of fertilizer salts grow and knit together, and the fertilizer sets up and becomes hard on drying. Changes in temperature where there is some water present also cause small amounts of certain fertilizer materials to go into or come out of solution, and as a result crystals knit together and the fertilizer hardens. When mixed fertilizers leave the plant they are usually in good physical condition.

When powdered organic materials, like cottonseed meal and tankage, are added to mixed fertilizers, the powder covers each particle of the other materials present and reduces setting up. When these organic materials are mixed with sulphate of ammonia and other ammonium fertilizers before limestone, basic slag, or dolomite is added, the loss of ammonia is materially reduced. These organic materials thus supply some nitrogen, phosphorus and potash, and reduce caking and the loss of ammonia.

Due to the fact that segregation of certain fertilizer materials in mixed fertilizers takes place and fine materials sift out of sacks in transportation and are lost by being blown away by wind during distri-

bution, there have been developed methods (2) for combining the materials into granules. The granules have approximately the same composition as the whole mixture. Mixtures containing organic materials do not granulate as easily as those containing only inorganic materials. Since high analysis fertilizers are low in organic materials, they are more suitable for granulation than are low analysis fertilizers.

Granulation of mixed fertilizers is accomplished by raising the moisture content of the mixture to 10 to 12% for granulation by the addition of water or steam and raising the temperature to 60°C. to 80°C. by ammoniation or the application of heat. The actual granulation is carried out by rolling in a drum and then drying in a rotary drier.

Preliminary tests with granulated mixed fertilizers (3) show that they are equal to regular mixed fertilizers. Theoretically, at least, there appears to be a possibility that the total phosphorus applied may be reduced by granulating fertilizers. For ordinary fertilizers, one possible advantage for granulation is that less superphosphate would be required for crop production, due to the phosphorus in granulated fertilizers coming in contact with less soil and being fixed in a less available form to a smaller extent. Granulated fertilizers have not been superior to regular fertilizers for cotton, due to the fact that the fertilizers are normally drilled in narrow bands, and high amounts of phosphorus have been used in the tests. Granulated superphosphate has been superior to regular superphosphate for hay production, and it should be superior for pastures, hay crops, and other crops where the phosphate is broadcast.

There were 1000 or more fertilizer analyses being sold in the United States before 1938. Florida, with a fertilizer consumption of 6 per cent of that of the whole United States, had over 300 analyses. The number of analyses sold is regulated in Mississippi, Louisiana, Oklahoma, Arkansas, and Texas. The number of analyses sold was regulated in all states during the second World War. The state agricultural officials and the fertilizer manufacturers select a list of analyses for the following year, which are the only fertilizers permitted to be sold in these states.

The most commonly used fertilizer analyses for the principal fertilized crops in states consuming 75 per cent of the total tonnage of fertilizers (6) are listed in Table 8. There are only 25 analyses which are commonly used, and it appears that these 25 analyses vary widely enough to meet the needs of most soils and crops. Many of the analyses .

Table 8.—THE USE OF FERTILIZER BY ANALYSES, CROPS, AND STATES.

State	Cotton		Corn		Potatoes		Wheat		Tobacco	
	Analysis	Amount per acre	Analysis	Amount per acre	Analysis	Amount per acre	Analysis	Amount per acre	Analysis	Amount per acre
Alabama.....	6-8-4	300	3-8-5	100	4-10-7	1000	....	....	....	....
Florida.......	3-8-5	300	4-8-4	200	4-8-8	2000	....	....	3-8-5	1000
Georgia......	4-8-4	350	3-9-3	200	....	....	2-10-4	200	3-8-5	1000
Indiana......	....	....	2-12-6	125	0-10-10	500	2-12-6	125	2-12-6	200
Maryland....	....	....	2-12-4	100	6-6-5	2000	2-8-5	250	4-8-12	800
Mississippi....	4-8-4	300	4-8-4	150	6-10-7	1000	....	....	....	....
North Carolina	3-8-3	400	3-8-3	200	6-6-5	2000	3-8-3	200	3-8-5	1000
New York....	....	....	4-12-4	300	4-8-7	2000	2-8-10	250	....	....
Ohio.........	....	....	2-12-6	125	4-8-8	1000	2-12-6	200	4-10-6	400
Pennsylvania..	....	....	2-8-5	200	2-8-10	1000	3-12-6	250	4-8-7	750
South Carolina	3-8-3	400	3-8-3	200	6-6-5	2000	3-8-3	200	3-8-5	600
Virginia......	0-10-4	400	3-8-3	200	6-6-5	2000	0-16-0	300	3-10-6	1000
Louisiana.....	4-8-4	200	....	....	4-12-4	800	....	....	....	....
Maine........	....	....	3-10-6	600	4-8-10	2000	....	....	....	....

listed are similar, and a much smaller number would probably supply the needs of the crops as accurately as fertilizer recommendations can be made.

The complete fertilizers listed above supplied 75% of the fertilizer used in the United States in 1938 and are represented fairly accurately by 3-3-2, 1-2-1, 1-3-1, 1-2-2 ratios and special purpose fertilizers (Table 9). The 1-2-1 fertilizer ratio is one of the most widely used ratios. The analyses which have a ratio approaching or equal to a 1-2-1 ratio are: 4-8-4, 6-12-6, 3-8-5, 6-10-7, and 5-10-5. Where fertilizer is used on the basis of recommendations, it is improbable that the one making the recommendation will be able to draw a line between the needs for a 4-8-4, 6-12-6, or 5-10-5, and one of the other analyses which vary slightly from the 1-2-1 ratio. In areas where one of these analyses predominates, it appears that all but one or two could be eliminated.

Table 9.—THE GROUPING OF MOST USED FERTILIZERS ANALYSES ACCORDING TO THE RATIO OF NITROGEN—PHOSPHATE—POTASH.

Ratio of nitrogen—phosphate—potash							
1-2-1	1-2-2	1-3-1	1-3-4	1-4-2	3-3-2	0-1-1	0-2-1
Analysis							
4-8-4	4-8-8	4-12-4	4-8-12	3-12-6	6-8-4	0-10-10	0-10-4
6-12-6	4-8-7	3-12-4	2-8-10	2-12-6	6-6-5	....	....
5-10-5	4-10-6	3-9-3	....	2-12-4	....	....	....
6-10-7	4-8-10	3-8-3	....	2-10-4	....	....	....
3-8-5	....	....	....	2-8-5	....	....	....
....	....	....	....	3-10-6	....	....	....

The analyses in the 1-3-1 ratio group are: 4-12-4, 3-12-4, 3-9-3, and 3-8-3. On the basis of recommendations one of the above analyses is probably as likely to meet the needs of the crops as accurately as recommendations can be made, and the fertilizers of an area might be limited to one of these ratios.

The 1-2-2 ratio group includes 4-8-8, 4-8-7, 4-8-10, and 4-10-6 analyses all of which are similar to the 4-8-8. Could not one of these analyses take the place of all in an area?

The 3-3-2 ratio group includes 6-8-4 and 6-6-5. Special purpose fertilizers are represented by 10-0-10.

The 1-3-4 ratio group includes 4-8-12 and 2-8-10.

The 1-4-2 ratio group includes 3-12-6, 2-12-6, 2-10-4, 2-8-5, and 3-10-6, all of which are similar to 3-12-6, which is typical of the group.

From the similarity of the fertilizer analyses used over the country as a whole, it appears that the needs of crops can be supplied by 1-1-1, 3-3-2, 1-2-1, 1-3-1, 1-2-2, 1-3-4, 1-4-2, 0-2-1, 0-1-1, and special purpose fertilizers. After establishment of the fertilizer ratios necessary to meet the crop requirements, the establishment of analyses is next in order. The analyses suggested are listed in Table 10. These 23 fertil-

Table 10.—FERTILIZER ANALYSES CORRESPONDING TO SUGGESTED FERTILIZER RATIOS.

Ratio	Illustrative analyses		
	Low	*Medium*	*High*
1-1-1	6-6-6	8-8-8	10-10-10
3-3-2	6-6-4	9-9-6	12-12-8
1-2-1	4-8-4	6-12-6	8-16-8
1-2-2	4-8-8	6-12-12	8-16-16
1-3-1	4-12-4	6-18-6	....
1-3-4	....	3-9-12	4-12-16
1-4-2	....	3-12-6	5-20-10
0-2-1	0-14-7	0-20-10	0-30-15
0-1-1	....	0-14-14	0-20-20

Special purpose..10-0-10, materials

izer analyses, together with a few special purpose analyses, should be sufficient to meet crop requirements as well as recommendations can be made for any soil where mixed fertilizers are used. If the number of fertilizer analyses were limited, it might not be entirely out of order to regulate the fertilizer materials entering each analysis. Such a regulation would stabilize the quality of fertilizers, and enable both the buyer and the seller to get together on common terms.

FERTILIZER CONTROL LEGISLATION

The quality of fertilizer can not be recognized by sight, and, as a result in the early days of the industry, farmers were sold materials of little or no value. Practices of unscrupulous dealers were responsible for laws being passed for inspection and chemical analyses of fertilizers. From time to time materials appear on the market which are sold as soil conditioners, the value of which is often less than the price asked. When materials are sold as soil conditioners, they usually can not be sold for fertilizer.

In 1873, Massachusetts passed an effective fertilizer control law (9), and since that date all states except Nevada have passed control laws. The laws provide for collecting samples of fertilizer for analysis, and the weights of the bags of fertilizer are checked. They require total nitrogen, available phosphoric acid, and water soluble potash to be guaranteed. Fertilizer brands are registered. Penalties are used against producers of fertilizer which fails to come up to the guarantee.

Alabama, North Carolina, South Carolina, Virginia, and Mississippi have passed laws which require that fertilizers be labeled "acid-forming" or "non-acid-forming" (9). The acidity of the fertilizer is checked by the control officials.

The nitrogen content of fertilizers is expressed as nitrogen in all states except South Carolina, where it is expressed as ammonia. The order in the analysis is phosphoric acid[1]—ammonia—potash in South Carolina, phosphoric acid—nitrogen—potash in Georgia, and nitrogen—phosphoric acid—potash in all other states (9).

In recent years the value of different sources of nitrogen and potash has been recognized, and as a result Mississippi requires that the sources of nitrogen be listed, and Alabama, California, Florida, Georgia, Idaho, Montana, Nebraska, Oregon, South Dakota, Virginia, and West Virginia require that all sources of materials be listed (9). Listing sources of materials is misleading unless the amount used is guaranteed and the control officials are able to enforce the guarantee, which is doubtful.

The fertilizer laws of South Carolina were set up to protect the farmer's interest better than that of any other state. The law requires that each fertilizer bag carry the source of each material in the fertilizer, its percentage by weight, and the plant nutrient content it supplies (9). The value of listing all materials present and giving their percentage in the mixture is based on the response of crops to different

[1]Phosphate

sources of nitrogen, phosphorus, and potash. It is doubtful if laws which require the listing of the percentages of materials from which fertilizers are derived can be enforced.

The enforcement of the fertilizer laws is usually left up to the state department of agriculture. The laws usually require fertilizer companies to buy tags from the state department of agriculture, the cost of which may be sufficient to pay the cost of enforcing the laws.

FERTILIZER MANUFACTURING PLANTS

The fertilizer manufacturing plants in each of the United States are listed in Table 11 (1). The types of plants are as follows:

 A. Complete plants, including equipment for making sulphuric acid, superphosphate, ammoniating superphosphate, and making mixed fertilizers.
 C. Complete, except sulphuric acid is not made.
 D. Dry mixing plants; all materials are bought.
 S. Sell complete fertilizers made under their brand name by someone else.
 NI. No information.

The complete plants have an advantage in that they make large tonnages, and they may be in better position when it comes to buying raw materials. They sell fertilizers over a large territory. The fertilizer business is seasonal, and many employees of complete plants may not be employed profitably for a large proportion of the time. The complete plants usually have a large volume of business, and they may process fertilizers at a lower cost per ton, but due to the fact that they sell over wide areas, their selling cost per ton may be higher than for dry-mixing plants.

Dry-mixing plants have an advantage in that their business is usually local, from the plant to the farm or to the local dealer. The operator of dry-mixing plants may be the superintendent and the salesman. The employees of the dry-mixing plants are probably not specialists, and they engage in other occupations during the off season.

The success of a dry-mixing fertilizer plant depends upon a large local business. Florida, Maine, Maryland, New Jersey, New York, Pennsylvania, South Carolina, Texas, and Washington have approximately 3 or more dry-mixing plants for each complete (A and C) fertilizer plant. If dry-mixing plants have been successful in these states, they would probably be successful in states where the ratio is lower, and larger tonnages of fertilizers are sold. The location of a

Table 11.—Number and Type of Fertilizer Plants Found by States.

	State	A	C	D	S	NI	Dry-mixing plants for each A and B plant
1.	Alabama	6	9	35	9	1	2
2.	Arizona	0	2	1	0	..	1
3.	Arkansas	3	2	10	1	1	2
4.	California	2	13	33	5	7	2
5.	Colorado	..	2	..	..	..	0
6.	Connecticut	..	1	8	1	..	8
7.	Delaware	..	..	8	..	3	..
8.	Dist. of Col	..	..	1	..	..	..
9.	Florida	5	2	52	1	..	7.
10.	Georgia	18	27	109	14	..	2
11.	Idaho	..	..	1	..	..	..
12.	Illinois	2	7	6	1	..	1
13.	Indiana	2	7	12	..	4	1
14.	Iowa	..	1	2	..	2	2
15.	Kansas	..	1	2	..	1	2
16.	Kentucky	..	3	3	..	..	1
17.	Louisiana	3	2	9	..	1	2
18.	Maine	..	1	16	..	..	16
19.	Maryland	7	4	32	2	3	3
20.	Massachusetts	1	2	6	1	..	2
21.	Michigan	1	2	6	1	3	2
22.	Minnesota	..	2	5	1	..	3
23.	Mississippi	2	6	11	2	3	2
24.	Missouri	1	..	..	..	1	..
25.	Montana	1	1	..	..	..	..
26.	Nebraska	..	1	..	..	..	..
27.	Nevada	..	..	..	..	1	..
28.	New Jersey	2	6	28	1	2	4
29.	New Hampshire	..	..	..	..	..	..
30.	New Mexico	..	..	1	..	..	..
31.	New York	1	4	23	..	2	5
32.	North Carolina	8	17	59	10	4	2
33.	North Dakota	..	..	1	..	..	..
34.	Ohio	9	11	15	3	4	1
35.	Oklahoma	..	..	1	..	..	..
36.	Oregon	..	..	5	..	1	..
37.	Pennsylvania	..	9	26	1	4	3
38.	Rhode Island	..	..	1	..	2	..
39.	South Carolina	10	5	66	11	..	4
40.	Tennessee	4	7	3	..	5	..
41.	Texas	3	1	20	..	7	5
42.	Utah	..	..	2	..	..	..
43.	Virginia	8	8	27	..	3	2
44.	Vermont	..	..	1	..	..	..
45.	Washington	..	2	13	..	1	7
46.	West Virginia	..	..	1	..	..	..
47.	Wisconsin	..	1	3	..	1	3

dry-mixing plant should, in the final analysis be based upon the business which may be obtained locally.

Small fertilizer plants may be operated in connection with some

other business which is seasonal. Cottonseed crushing plants and gins have been operated successfully in connection with fertilizer plants. The power used in these plants may also be used in the fertilizer plant.

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(15)

Buying Fertilizers

Fertilizers are bought for profit.

The most profitable fertilizer produces the highest return per dollar invested. Fertilizers of different analyses may be bought factory-mixed, or materials which contain the desired plant nutrients may be bought for home-mixing. The differences between fertilizers which determine the profit which may be made are:

1. Source of nitrogen
2. Source of phosphorus
3. Source of potash
4. Acidity of fertilizer
5. Time of application of nitrogen
6. Analysis of fertilizer
7. Effect on the available lime, phosphate, and potash
8. Rate used per acre
9. Cost

The effect of all of the above listed factors on the yields of crops has been determined in separate tests. It would be impractical to include all of the variables in one test. However, it does appear practicable to combine the data in such a way that their influence is easily observed. In combining the data it is necessary to start with a given set of field data, to which the effects of other factors are added or subtracted. The data selected for use are an average of the response of cotton to rates of 4-8-4 and different analysis fertilizers on the short-leaf pine upland soils of Mississippi (1)[1].

In the interpretation of the data, 1940 prices of fertilizer were used:

Fertilizer	Price per ton	
4-8-4	$26.57	
6-8-4	30.17	
Superphosphate (20%)	22.00	
Muriate of potash (50%)	41.00	
Nitrate of soda	36.00	
Sulphate of ammonia	36.00	
Ammonium nitrate	50.00	(estimated)
Dolomite	7.50	

Seed cotton was valued at 5 cents per pound. These prices are much lower than exist for seed cotton and mixed fertilizers at the present time. However, the data as presented are illustrations of the interpre-

[1] Numbers in parenthesis refer to the source of information, page 372.

tation of data, and the local prices which exist at any time may be used in the interpretation of the available data.

Fertilizer analyses tests have usually been conducted using a definite rate of each analysis. Where sources of materials are tested a given rate of plant nutrients is usually used. With rate constant the variations in cost introduce a variable which makes the interpretation of the data difficult. In the Mississippi tests, where 600 pounds per acre of different analyses were used, the cost per acre varied from $7.21 to $10.14, and $5.00 to $9.02 per acre on the basis of factory-mixed and home-mixed prices, respectively (1). The data for the home-mixed fertilizers on the shortleaf pine uplands are as follows:

FIG. 1—THE RELATION OF AMOUNT AND COST OF 4–8–4 FERTILIZER TO THE INCREASE IN YIELD OF SEED COTTON

| $ 3.99 | $ 7.97 | $ 11.96 | $ 15.94 | $ 23.91 | $ 31.88 |

COST OF FACTORY-MIXED FERTILIZER

| $ 3.16 | $ 6.32 | $ 9.48 | $ 12.64 | $ 18.96 | $ 25.28 |

COST OF HOME-MIXED FERTILIZER
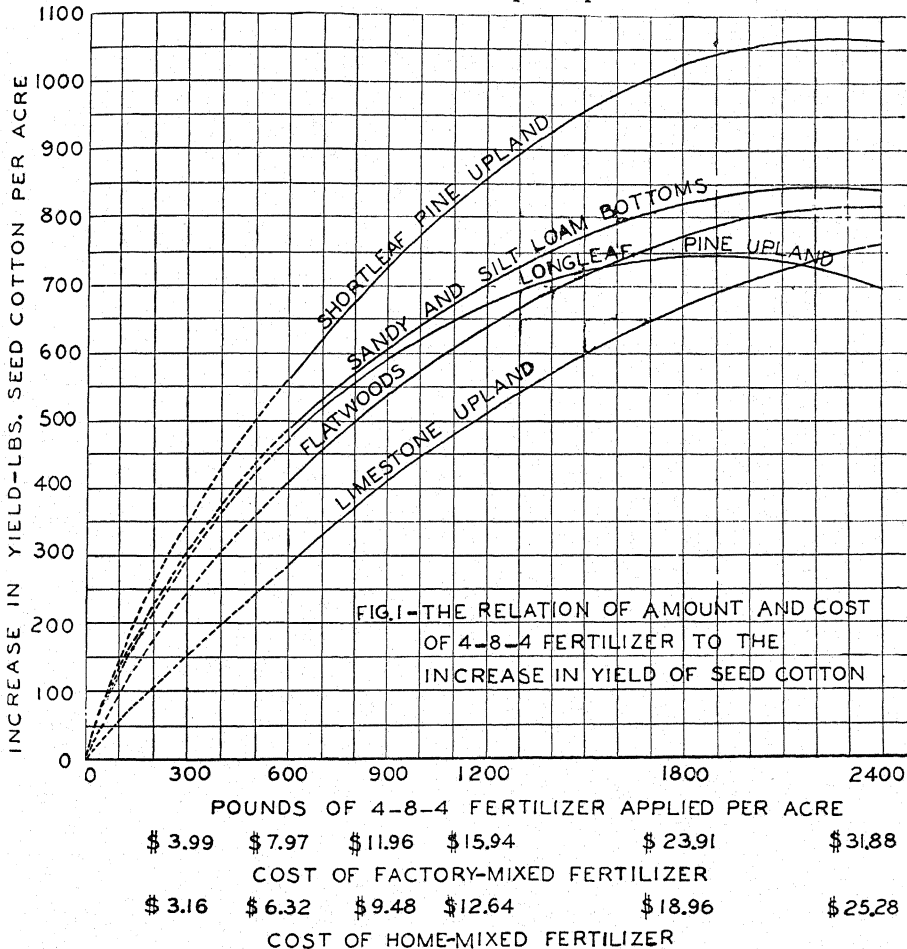
Analysis (600 lbs. per acre)	Increase in yield, lbs. seed cotton	Value at 5 cents	Cost of fertilizer	Profit per acre	Profit per dollar invested
4-4-4............	564	$28.20	$5.00	$23.20	$4.74
4-8-4............	561	28.05	6.32	21.73	3.44
6-8-4............	747	37.35	7.67	29.68	3.87
8-8-4............	774	38.70	9.02	29.68	3.29

The profit per acre and the profit per dollar invested in the different analyses suggest different fertilizers to be most profitable. With the same investment in fertilizers, the interpretation of the data would be based on profit per acre.

The difference in the cost of the different analysis fertilizers was eliminated by the use of the curve, on shortleaf pine upland soils in Figure 1. The increase in yield was calculated for $7.97 spent for fertilizer on one acre, and $100 spent for fertilizer on 12.55 acres. In some cases data on the same tonnage of different sources of materials and costs were included in the calculations.

Where 600 pounds per acre of 4-8-4[1] fertilizer was used the increase in yield of seed cotton was 561 pounds per acre, or 7,039 pounds on 12.55 acres. The increase in yield for 600 pounds of 8-8-4 per acre costing $10.14 was 774 pounds of seed cotton. With $10.14 invested in the 4-8-4 the increase in yield was 663 pounds of seed cotton per acre. Multiplying 7,039 by 774 and dividing by 663 gives 8,217 pounds of seed cotton for $100 invested in 8-8-4, as compared to 7,039 pounds for $100 invested in 4-8-4 fertilizer. The 8-8-4 is evidently more profitable than the 4-8-4 fertilizer.

In eliminating differences in cost of factory-mixed and home-mixed fertilizers, the rate of application per acre was higher for the home-mixed fertilizers, due to the fact that home-mixed fertilizers were cheaper. Consequently the calculations for the increase in yield for $100 worth of home-mixed 4-8-4 was based upon the increase in yield from $7.97 worth of home-mixed fertilizer per acre applied to 12.55 acres. The increase in yield for 757 pounds of home-mixed 4-8-4 fertilizer costing $7.97 was 651 pounds of seed cotton per acre or 8,168 pounds for $100 worth applied to 12.55 acres. The other calculations were made similarly.

The source of nitrogen used in the tests was nitrate of soda. Since most of the nitrogen in mixed fertilizers is ammonium sulphate and related sources, a deduction of 0.83 pounds of seed cotton per pound

[1]The fertilizer was derived from nitrate of soda, superphosphate, and muriate of potash.

ot nitrogen (7) was made for factory-mixed fertilizers (see page 8).

The accumulated increases in yields for $100 invested in the different analysis fertilizers and applied to 12.55 acres are:

Analysis	Tons on 12.55 acres		Increase in yield, pounds of seed cotton	
	Factory-mixed	Home-mixed	Factory-mixed	Home-mixed
4-4-4...............	4.14	6.00	7,216	9,518
4-8-4...............	3.76	4.75	6,789	8,168
6-8-4...............	3.31	3.91	8,262	9,609
8-8-4...............	2.96	3.33	7,824	8,942

Selecting the most suitable analysis may be made on the basis of the highest yield obtained with either factory-mixed or home-mixed fertilizers. With home-mixed fertilizers 4-4-4 and 6-8-4 were equally efficient, while 6-8-4 was the most efficient factory-mixed fertilizer.

Nitrate of soda was superior to both sulphate of ammonia and ammonium nitrate where the acid-forming properties of the last named sources were neutralized with dolomite (see pages 6, 8, 10, 11). Ammonium nitrate and sulphate of ammonia have approximately the same efficiency for crop production when the acid properties of both are neutralized with dolomite. In 358 experiments where 36 pounds of nitrogen was applied, sulphate of ammonia and dolomite made 30 pounds of seed cotton per acre less than was produced by nitrate of soda. The difference in favor of nitrate of soda was 0.83 pounds of seed cotton per pound of nitrogen, or 389 pounds more seed cotton was made where 3.91 tons of 6-8-4 fertilizer was applied on 12.55 acres when the source of nitrogen was nitrate of soda, rather than sulphate of ammonia.

From the use of the curve it was found that 4.50 tons of 6-8-4 fertilizer from nitrate of soda, superphosphate, and muriate of potash produced 10,328 pounds of seed cotton. The 4.50 tons of 6-8-4 contains 540 pounds of nitrogen; multiplying 540 times 0.83 gives 448 pounds of seed cotton reduction in yield for ammonium nitrate and dolomite as compared to nitrate of soda and subtracting 448 from 10,328 gives 9,680 pounds of seed cotton for ammonium nitrate and dolomite. The data are as follows:

Analysis	Tons on 12.55 acres	Source of nitrogen	Cost	Increase in yield, pounds seed cotton
6-8-4.........	3.91	Nitrate of soda	$100	9,609
6-8-4.........	3.91	Sulphate of ammonia[1]	100	9,220
6-8-4.........	4.50	Ammonium nitrate[1]	100	9,680

[1]Neutralized with dolomite.

The value of 389 pounds of seed cotton is $19.45, which is the increase in income for using nitrate of soda instead of sulphate of ammonia. Ammonium nitrate and dolomite made practically the same increase in yield as nitrate of soda, due to the fertilizer being used at a higher rate per acre.

The difference in cost of home-mixed and factory-mixed fertilizers produces considerable difference in the profits made. In the calculations presented below the fertilizers were neutral, and the nitrogen in the mixed fertilizers was considered equal to that in ammonium nitrate:

Analysis	Tons on 12.55 acres	Source of nitrogen	Basis of price	Cost	Increase in yield, pounds of seed cotton
6-8-4	3.31	Ammonium nitrate	Home-mixed	$73.51	8,262
6-8-4	4.50	Ammonium nitrate	Home-mixed	100.00	9,680
6-8-4	3.31	Mixed	Factory-mixed	100.00	8,262

According to the calculations equal yields of seed cotton were obtained from $73.51 invested in home-mixed and from $100 invested in factory-mixed fertilizers. Apparently $26.49 could be saved by home-mixing; however, when $100 was spent for both home-mixed and factory-mixed fertilizers, $74.20 more profit was made from home-mixed fertilizers.

The data show that $26.49 can be saved by home-mixing 3.31 tons of 6-8-4 fertilizer, or $74.20 can be made by home-mixing 4.50 tons of 6-8-4 fertilizer costing $100.

Side dressing cotton with one-third to one-half of the nitrogen increased the average yield of seed cotton 113 pounds per acre in 23 tests conducted throughout the Southeast (2, 3, 4). On the basis of 3.91 tons of fertilizer for 12.55 acres of cotton, the data are as follows:

Analysis	Time of application of nitrogen	Tons on 12.55 acres	Cost	Increase in yield, lbs. seed cotton
6-8-4..........	All under	3.91	$100	9,609
6-8-4..........	⅓ to ½ side dressing	3.91	100	11,027

The data show that 1,418 pounds more seed cotton valued at $70.90 was made by side dressing with one-third to one-half of the nitrogen.

For preplanting application where nitrate of soda was used as a side dressing, sulphate of ammonia was superior to nitrate of soda. The difference was 31 pounds of seed cotton per acre in 59 experiments or 389 pounds on 12.55 acres where 3.91 tons (6) of fertilizer was used:

Analysis	Sources of nitrogen		Equal tons 6-8-4	Increase in yield, pounds seed cotton
	Under	Side dressing		
4-8-4.......	Nitrate of soda	Nitrate of soda	3.91	11,027
4-8-4.......	Sulphate of ammonia	Nitrate of soda	3.91	11,416

The value of 389 pounds of seed cotton is $19.45. The superiority of sulphate of ammonia to nitrate of soda for preplanting where nitrate of soda was used as a side dressing is attributed to the preference of young cotton for ammonia nitrogen. With ammonia nitrogen many young plants grow off more rapidly than with nitrate nitrogen.

The use of dolomite to change acid-forming to neutral fertilizer increased the yield of seed cotton 577 pounds on 12.55 acres in 358 experiments (7) in Alabama:

Analysis	Acidity	Tons on 12.55 acres	Cost	Increase in yield, pounds seed cotton
6-8-4.........	Acid-forming	3.31	$100	7,685
6-8-4.........	Neutral	3.31	100	8,262

The value of 577 pounds of seed cotton is $28.85. The response to dolomite is usually greater after several year's use of acid-forming fertilizers than where they are first used.

Where soils have a good supply of lime, dolomite is not needed. Data were presented on page 289 which raise a question concerning the use of dolomite in factory-mixed fertilizers. The use of acid-forming

high analysis fertilizers and lime separately is cheaper than low analysis neutral fertilizers.

Increasing the fertilizer analysis from 4-8-4 to 6-12-6 increased the yield of seed cotton 767 pounds from $100 invested in factory-mixed fertilizers on 12.55 acres:

Analysis	Tons	Cost	Increase in yield, pounds seed cotton
4-8-4...................	3.76	$100	6,789
6-12-6.................	2.88	100	7,556

The value of 767 pounds of seed cotton is $38.35.

The ammoniation of superphosphate decreased its value very sharply in neutral fertilizers in both Alabama (6) and Georgia[1]. Based on 185 experiments in Alabama, if the phosphate in mixed fertilizers has been ammoniated with 5% ammonia, the yield of seed cotton would be 60 pounds per acre less where 60 pounds of phosphate is used, or 1 pound of seed cotton less for each pound of phosphate ammoniated with 5% ammonia. This is a reduction of 160 pounds of seed cotton per ton of fertilizer containing 8% phosphate, or 530 pounds of seed cotton valued at $26.50 for 3.31 tons of 6-8-4 fertilizer.

In the Georgia experiments, the ammoniation of superphosphate with 3% ammonia reduced the yield 77 pounds of seed cotton per acre where 60 pounds of phosphate in neutral fertilizers was used per acre. The reduction in yield was 1.283 pounds of seed cotton per pound of phosphate applied, or a reduction in yield of 9.4 pounds of seed cotton per pound of nitrogen used in the ammoniation of superphosphate. The use of 1.86% ammonia for the ammoniation of superphosphate was satisfactory; increasing the ammonia used in the ammoniation of superphosphate from 1.86 to 3% reduced the yield of seed cotton 25 pounds for each pound of additional ammonia nitrogen used in the ammoniation of superphosphate. On the basis of the ammoniation of superphosphate with 3.0% ammonia reducing the yield of seed cotton 1.283 pounds per pound of phosphate used, 3.31 tons 6-8-4 containing 530 pounds of phosphate produced 530 x 1.283, or 680 pounds of seed cotton less than if regular superphosphate had been used. Subtracting 680 from 5,982 gives 5,302 pounds of seed cotton from 3.31 tons of fertilizer containing sulphate of ammonia, dolomite, 3.0% ammonia ammoniated superphosphate, and muriate of potash. The

[1]Personal communication from R. P. Bledsoe.

differences for ammoniated superphosphate in acid fertilizers were smaller.

In the Mississippi experiments the ammoniation of superphosphate with 4.78 per cent ammonia in neutral fertilizers (see page 288) reduced the yield 5.29 pounds of seed cotton per pound of phosphate. The reduction in yield for 3.31 tons of 6-8-4 fertilizer, which contains 530 pounds of phosphate, is 530 x 5.29 or 2784 pounds of seed cotton. The data for neutral fertilizers from Georgia and Mississippi are:

Analysis	Percent ammonia in superphosphate	Tons on 12.55 acres	Cost	Increase in yield, pounds seed cotton
6-8-4............	0.0	3.31	$100	8,262
6-8-4[1]...........	3.0	3.31	100	7,582
6-8-4[2]...........	4.78	3.31	100	5,478

[1]Georgia.   [2]Mississippi.

The data show that 2,784 pounds less seed cotton was made where 4.78% ammonia ammoniated superphosphate was used, and 680 pounds less where the ammonia in the superphosphate was 3.0%. The value of 2,784 pounds of seed cotton is $139.20, while that of 680 pounds is $34.00.

It was pointed out in Chapter 11 that the present official method for determining available phosphorus in fertilizers does not offer sufficient security that mixed fertilizers containing low percentages of phosphate will not be ammoniated high enough to materially reduce the availability of the phosphorus.

High grade muriate of potash containing approximately 60 per cent potash is the most commonly used source of potash. Manure salts contain approximately 40 per cent pure muriate of potash and 55 to 60 per cent table salt. For those crops which respond to the soda in table salt, consideration should be given to the use of manure salts instead of high grade muriate of potash in home-mixed fertilizers.

Due to the fact that the table salt in manure salts tends to give mixed fertilizers poor physical properties, manure salts is not commonly used in mixed fertilizers.

Natural organic sources of nitrogen, like cottonseed meal and tankage, are preferred as part of the nitrogen by some farmers. Without taking cost into consideration, there is some evidence to justify their choice. In a few cases where deriving part of the nitrogen from natural organics is superior to deriving all of it from inorganic sources, its

superiority is probably due to the fact that the natural organic sources of nitrogen contain small quantities of the less common elements which are used by plants. From the standpoint of the nitrogen present, the natural organics do not have any advantage over other sources of nitrogen, particularly where side dressing is practiced. The natural organic sources of nitrogen cost about three times as much as other sources at the present time.

Insoluble synthetic organic nitrogen may be produced where super-phosphate is ammoniated with a solution containing ammonia, urea, and ammonium formate. The insoluble synthetic organic source of nitrogen does not contain the less common elements contained in the natural organic sources of nitrogen. In chemical analysis the insoluble synthetic organic nitrogen is determined as organic nitrogen, just as the nitrogen in cottonseed meal is determined as organic. No data have been reported on the response of crops to insoluble synthetic organic nitrogen. Since little natural insoluble inorganic nitrogen is present in fertilizers, the desirability of stating that insoluble organic nitrogen is contained in fertilizers may be open to question.

The amount of materials necessary to give the same amount of plant nutrients as contained in one ton of fertilizer of a given analysis may be calculated.

Problem: Calculate the amount of nitrate of soda (16% nitrogen), superphosphate (20% phosphate), and muriate of potash (60% potash) required to supply the same amount of nitrogen, phosphorus, and potash as one ton of 6-8-4 fertilizer contains.

The 6-8-4 analysis fertilizer contains 6% nitrogen, 8% phosphate, and 4% potash. One tone of 6-8-4 fertilizer contains

$$2,000 \times .06 = 120 \text{ pounds of nitrogen}$$
$$2,000 \times .08 = 160 \text{ pounds of phosphate}$$
$$2,000 \times .04 = \ \ 80 \text{ pounds of potash}$$

The materials required to supply the plant nutrients are:

Nitrogen, $120 \div .16 = 750$ pounds of nitrate of soda
Phosphorus, $160 \div .20 = 800$ pounds of superphosphate
Potash, $80 \div .60 = 133$ pounds of muriate of potash
                    Total 1683 pounds

It will be observed that the mixture contains only 1,683 pounds of materials instead of 2,000 pounds. The 1,683 pounds of fertilizer materials contain 120 pounds of nitrogen, 160 pounds of phosphate, and 80 pounds of potash, which are the quantities of these plants nutrients contained in one ton of 6-8-4 fertilizer.

The analysis of the home-mixed fertilizer is obtained as follows:

$$120 \div 1,683 \times 100 = 7.1\% \text{ nitrogen}$$
$$160 \div 1,683 \times 100 = 9.5\% \text{ phosphate}$$
$$80 \div 1,683 \times 100 = 4.8\% \text{ potash}$$

The actual analysis of the home-mixed fertilizer is 7.1-9.5-4.8. The analysis may be reduced to a 6-8-4 by the addition of 317 pounds of sand or other material. However, in home-mixing it is customary to omit the sand and use a lower rate per acre.

Where 600 pounds per acre of 6-8-4 fertilizer is desired, the amount of 7.1-9.5-4.8 fertilizer required to supply the same amount of plant nutrients is:

$$600 \text{ (lbs. 6-8-4)} \times 1,683 \div 2,000 = 505 \text{ pounds of 7.1-9.5-4.8}$$

The same amount of plant nutrients may be supplied by 505 pounds of 7.1-9.5-4.8 fertilizer as by 600 pounds of 6-8-4.

The pounds of fertilizer materials necessary for one ton of fertilizer with different percentages of nitrogen, phosphate, and potash may be found in Table 1. As an illustration, the amount of materials required to make a ton of 6-8-4 from nitrate of soda (16 per cent nitrogen), superphosphate (20 per cent phosphate), and muriate of potash (50 per cent potash) are:

	Pounds
Nitrate of soda......................	750
Superphosphate......................	1,000
Muriate of potash....................	160
	1,910

The 6-8-4 fertilizer contains 6 per cent nitrogen, 8 per cent phosphate, and 4 per cent potash. If nitrate of soda which contains 16 per cent nitrogen is used, the table shows that 750 pounds of nitrate of soda is needed. If 20 per cent superphosphate is used, the table shows that 1000 pounds is required. Likewise, it is found that 160 pounds of 50% muriate of potash is required.

The mixture contains only 1,910 pounds; however, it contains 120 pounds of nitrogen, 160 pounds of phosphate, and 80 pounds of potash, just as one ton of 6-8-4 fertilizer contains.

When fertilizers are home mixed on the basis of a ton of a given analysis fertilizer, the pounds of material rarely add up to an even ton. When the total weight is less than a ton, less fertilizer is required to supply a given amount of nitrogen, phosphate, and potash. When the total weight is more than one ton, more fertilizer is required to supply a given amount of nitrogen, phosphorus, and potash.

Calculating the exact amount of the different materials required for making a ton of fertilizer is of value for comparing the cost of

Table 1.—Pounds of Fertilizer Materials Required in Formulating Mixed Fertilizers.

Percent of nutrient in material	Percent of nutrient in the fertilizer formula									
	2	4	6	8	10	12	14	16	18	20
4	1000	2000	......	......	......	......	......	......	......	......
6	667	1333	2000	......	......	......	......	......	......	......
8	500	1000	1500	2000	......	......	......	......	......	......
10	400	800	1200	1600	2000	......	......	......	......	......
12	333	667	1000	1333	1667	2000	......	......	......	......
14	286	571	857	1143	1429	1714	2000	......	......	......
16	250	500	750	1000	1250	1500	1750	2000	......	......
18	222	444	667	889	1111	1333	1556	1778	2000	......
20	200	400	600	800	1000	1200	1400	1600	1800	2000
22	182	364	545	727	909	1091	1273	1455	1636	1818
24	167	333	500	667	833	1000	1167	1333	1500	1667
26	154	308	462	615	769	923	1077	1231	1385	1538
28	143	286	429	571	714	857	1000	1143	1286	1429
30	133	267	400	533	667	800	933	1067	1200	1333
32	125	250	375	500	625	750	875	1000	1125	1250
34	118	235	353	471	588	706	824	941	1059	1176
36	111	222	333	444	556	667	778	889	1000	1111
38	105	211	316	421	526	632	737	842	947	1053
40	100	200	300	400	500	600	700	800	900	1000
42	95	190	286	381	476	571	667	762	857	952
44	91	182	273	364	455	545	636	727	818	909
46	87	174	261	348	435	522	609	696	783	870
48	83	167	250	333	417	500	583	667	750	833
50	80	160	240	320	400	480	560	640	720	800
52	77	154	231	308	385	462	538	615	692	769
54	74	148	222	296	370	444	519	593	667	741
56	71	143	214	286	357	429	500	571	643	714
58	69	138	207	276	345	414	483	552	621	690
60	67	133	200	267	333	400	467	533	600	667
62	65	129	194	258	323	387	452	516	581	645

home-mixed and factory-mixed fertilizers. The approximate ratio of materials can be obtained from the calculations, after which approximation by sacks and fractions of sacks is entirely satisfactory. For home-mixing fertilizers, the formulas listed in Table 2 will be approximately equal to the indicated ratios.

If 16% superphosphate and 50% muriate of potash are used with nitrate of soda and ammonium nitrate, the materials listed make fertilizers corresponding closely to the indicated ratios. Where 60% potash and 20% superphosphate are used, there is more variation from the indicated ratio. The ratios are also slightly different where cyanamid and sulphate of ammonia are used. However, the amounts of materials do not vary from the indicated ratios sufficiently to be of consideration,

Table 2.—FORMULAS FOR HOME-MIXED FERTILIZERS.

Ratio	1-2-1	1-3-1	1-2-2	3-3-2
Representative analyses	(4-8-4) (6-12-6)	(4-12-4) (3-9-3)	(4-8-8) (6-12-12)	(6-8-4) (6-6-5)
Material		100-pound sacks of fertilizer		
	Using nitrate of soda			
Nitrate of soda..............	1	1	1	1
Superphosphate..............	2	3	2	1
Muriate of potash...........	⅓	⅓	⅔	⅓
	Using ammonium nitrate			
Ammonium nitrate...........	½	½	½	½
Superphosphate..............	2	3	2	1
Muriate of potash...........	⅓	⅓	⅔	⅓
	Using sulphate of ammonia			
Sulphate of ammonia.........	1	1	1	3
Superphosphate..............	2	3	2	3
Muriate of potash...........	⅓	⅓	⅔	⅔
Dolomite..................	1½	1½	1½	4½
	Using cyanamid			
Cyanamid..................	1	1	1	3
Superphosphate..............	2	3	2	3
Muriate of potash...........	⅓	⅓	⅔	⅔

due to the lack of complete information on the ratios actually needed. The above formulas may be varied to make special purpose fertilizers. Where it is desired to increase nitrogen, phosphate, or potash, it is sufficiently accurate to use the materials by quarters, thirds, or halves of sacks. Accurate weighing of the materials is not necessary, and it probably has no advantage over the simple procedure outlined above.

Fertilizer may be mixed on a floor, in a wagon bed, or on a hard area of ground. Sufficient mixing is obtained when the fertilizer materials are piled up and then transferred with a shovel to a new pile 3 or 4 times, taking care to put each shovel full on top of the new pile. It is desirable to apply most home-mixed fertilizers soon after mixing. Where fertilizers are mixed several days in advance of applying, one sack of cottonseed meal per ton will keep the fertilizer from getting hard and lumpy. However, the cost of the fertilizing elements in cottonseed meal is about three times as much as in inorganic sources.

When sulphate of ammonia is mixed with basic slag or calcium limestone, ammonia gas is given off if the materials are damp. The loss of ammonia may be prevented by mixing one sack of cottonseed meal with 5 sacks of sulphate of ammonia before mixing with the basic slag or limestone.

After a year of low income, farmers often use fertilizers which contain practically no nitrogen and potash. As an illustration (1) in Newton County, Mississippi, the average fertilizer ratio was 5.5-8-2.5 in 1930, and 6-8-4.4 in 1938, but after the low income year of 1931, it was 0.9-8-0.7. The decrease in the use of nitrogen and potash was probably due to the fact that superphosphate was the only fertilizer used in many cases.

The phosphate accumulated during 6 years of fertilization with 200 pounds of superphosphate per acre increased the yield 179 pounds of seed cotton per acre on the seventh year when no phosphate was used (unpublished, Mississippi data). The use of nitrogen for cotton on soils which had been fertilized with 1,200 pounds of superphosphate in a 4-8-4 fertilizer over a six-year period enabled cotton to give an excellent response to the phosphorus applied on the previous years. When money for buying fertilizers is short, it therefore, appears that nitrogen only may be used in the South, where complete fertilizers have been used previously. The residual effect of the phosphate and potash applied previously should be sufficient for crops to give a good response to nitrogen only.

The response of cotton to rates of 4-8-4 fertilizer on five soil areas in Mississippi (1) is illustrated in Figure 1. The shortleaf pine upland soils of the central and northern part of the state were most responsive to fertilizer; and the sandy loam bottom, longleaf pine upland soils (of South Mississippi), the flatwoods, and the limestone upland soils were less responsive.

The curves show that each successive addition of fertilizer produces less increase in yield than the preceding addition. With a given cost of fertilizer and price of seed cotton the most profitable rate may be easily determined.

A profitable response to fertilizers is not always obtained, due among other things to seasonal variations. For this reason farmers usually use less fertilizer each year than would be most profitable over a period of years.

The effect of natural soil fertility upon the response of crops to fertilizers is shown by the following data (8) from Alabama:

Treatment—lbs. per acre			Yield—pounds seed cotton per acre without fertilizer			
			0-to 250	250 to 500	500 to 750	750 to 1000
Nitrate of soda	Super-phosphate	Muriate of potash	Number of experiments			
			49	57	37	6
			Increase in yield—pounds seed cotton per acre			
100	200	25	303	352	323	325
200	400	50	493	593	518	568
300	600	75[1]	650	743	622	..

[1]Results not strictly comparable: only 32 experiments in 0-250 group; 50 experiments in 250-500 group; and 34 experiments in 500-750 group.

There is apparently no relation between the natural productivity of the soil and the response of cotton to fertilizers. However, it is generally recognized that the response to fertilizers is uncertain when applied to soils on which crops sometimes fail before maturity on account of poor drainage or other soil conditions.

SUMMARY AND CONCLUSIONS

The data on the factors which influence the profit made on money invested in fertilizers were reviewed and combined to illustrate their influence on the profit made from investment in cotton fertilizer. The profit which may be made on money invested in fertilizer is determined by:

1. Source of nitrogen
2. Source of phosphorus
3. Source of potash
4. Acidity of the fertilizer
5. Analysis of the fertilizer
6. Time of applying the nitrogen
7. Cost of the fertilizer.

On the basis of the calculations presented the above factors may be responsible for $100 invested in fertilizer producing from 5,478 to 11,416 pounds of seed cotton on 12.55 acres, or a difference of 5,938 pounds of seed cotton. The value of 5,938 pounds of seed cotton is $296.96 at 5 cents per pound. Greater differences may be obtained than were illustrated.

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(16)

The Effect of Placement of Fertilizers on the Yield and Stand of Crops

Placement of fertilizer relative to the seed has received considerable attention during the last 15 years. The position which fertilizers are commonly placed relative to the seed is closely tied up with the method of preparing the seed bed and planting and cultivating the crop. The cotton crop receives more fertilizer than any other crop grown in the United States.[1] Cotton is usually planted on a bed (or ridge) 4 to 8 inches high. Before the last war the fertilizer most commonly used before planting cotton was a 4-8-4, and the rate of application was usually from 200 to 400 pounds per acre. Many farmers side dress their cotton with some source of nitrogen; nitrate of soda is most often used.

Cotton fertilizers are commonly applied in the water furrow, after which the land is bedded. When the seed bed has been completed, harrowed off and planted, the fertilizer is usually 3 to 4 inches below the seed. Cotton fertilizers are also applied in a shovel furrow in the top of the bed in certain sections of the cotton belt. The furrow is filled with a harrow, and the seed are planted over the fertilizer. In this case the fertilizer may not be more than two inches below the seed.

The effect of placement of 800 pounds of 4-8-4 fertilizer relative to the seed on the stand of cotton (10)[2] is shown by the data in Table 1. A good stand of cotton was obtained with all of the fertilizer placements except where all of the fertilizer was placed in the top of the bed. With the fertilizer placed in the top of the bed, cotton came up slowly, and in two cases fewer plants came up, but there were sufficient plants to produce good yields. Placing one-fourth of the fertilizer (200 pounds per acre) in the top of the bed was not injurious to the stand.

The effect of placement of 800 pounds of 4-8-4 fertilizer on the yield of seed cotton (10) is shown by the data reported in Table 2. The standard farm practice of applying fertilizer in a band in the water

[1] In recent years corn has received more fertilizer than cotton.
[2] Numbers in parenthesis refer to the source of information, page 391.

Table 1.—THE EFFECT OF PLACEMENT OF 800 POUNDS OF 4-8-4 FERTILIZER ON THE STAND OF COTTON.

Fertilizer placement	Rocky Mt. N.C.(1) Norfolk sandy loam	Flor- ence S. C. Norfolk f. s. loam	Colum- bia S. C. Norfolk course sand	Clem- son S. C. Cecil sandy loam	Tifton Ga. Tifton sandy loam	State Col. Miss. Ruston f. s. loam	1935 Aver- age (1)	1934 Aver- age
	Number of plants per 50 feet of row							
No fertilizer—flat land......	36	343	263	287	275	217	277	271
No fertilizer—bedded land...	5	357	185	344	323	93	260	262
At planting								
Band 1½" to one side, 2" below seed level—flat.....	29	217	247	310	229	207	242	270
Band 1½" to each side, 2" below seed level—flat.....	29	282	250(2)	295	272	211	262	263
Band 2½" to each side, 2" below seed level—flat.....	34	365	250	295	283	216	282	278
Band 3½" to each side, 2" below seed level—flat.....	...	361	241	317	321	190	286	278
¼ in surface soil, balance 2½" each side—flat.......	15	365	185	320	292	195	271	274
Band 2½" each side, 3" be- low seed level—bedded....	38	393	245	308	288	201	287	281
In furrow in top of bed— separate operation— bedded.................	2	353	84	320	163	162	216	...
"Bedded on" in advance								
1¾" band, 3" under seed....	1	254	161	348	306	88	231	259
Band 2½" each side, 3" be- low seed level...........	7	390	179	348	318	142	275	256
Mixed with soil to depth 3" under seed.............	3	286	191	331	278	142	246	236

(1) Omitted from 1935 average because of erratic results due to unfavorable growing season.
(2) Columbia test not conducted 1935—stand and yield computed from previous relative standing.

furrow and bedding on it 10 days before planting was represented by the placement 1¾ inch band, 3 inches under the seed 10 days in advance of planting. The average yield of seed cotton for this placement in 1934-'35 was 1,169 pounds of seed cotton per acre, which was exceeded by only four other placements, and the differences were 7, 12, 22, and 35 pounds of seed cotton per acre, which are probably not significant. Placing the fertilizer in a band 2½ inches to each side and 3 inches below the level of the seed at planting time produced practically the same yield of seed cotton in 1935 as the standard farm practice of applying it before planting. In 1934, side placement of the fertilizer at planting time produced 63 pounds more seed cotton than the standard farm method of applying fertilizer. There were variations in the data which suggest that the difference may have been due to chance. The data show that side placement of the fertilizer at planting time is a very satisfactory method for applying fertilizers where suitable machinery is available.

Placing the fertilizer in a "band 2½ inches to each side of, and 3 inches below" the seed 10 days before planting made practically the

Table 2.—Yield of Seed Cotton for Different Placements of 800 Pounds Per Acre of 4-8-4 Fertilizer on Flat and on Bedded Land at Time of Planting and "Bedded On" in Advance of Planting.

Fertilizer placement	Location and soil type								
	Rocky Mt. N.C.(1)	Florence S.C.	Columbia S.C.(2)	Clemson S.C.	Tifton Ga.	State Col. Miss.	1935 Average (1)	1934 Average	1934 1935 Average
	Norfolk sandy loam	Norfolk f.s. loam	Norfolk course sand	Cecil sandy loam	Tifton sandy loam	Ruston f. s. loam			
	Yield—lbs. seed cotton per acre								
No fertilizer—flat land.	548	1,223	340	1,410	158	505	727	474	601
No fertilizer—bedded land..............	174	1,387	322	1,365	114	426	723	483	603
At planting Band 1½" to one side, 2" below seed level —flat.............	1,120	1,824	769	1,506	548	1,152	1,160	1,157	1,159
Band 1½" to each side, 2" below seed level —flat.............	996	1,826	770	1,510	574	1,130	1,162	1,153	1,158
Band 2½" to each side, 2" below seed level —flat.............	946	1,901	746	1,542	656	1,083	1,186	1,170	1,178
Band 3½" to each side, 2" below seed level —flat.............	....	1,901	693	1,722	719	1,165	1,240	1,098	1,169
¼ in surface soil, balance 2½" each side —flat.............	821	1,875	703	1,711	607	1,170	1,213	1,169	1,191
Band 2½" each side, 3" below seed level —bedded..........	1,469	1,772	794	1,769	668	1,095	1,220	1,187	1,204
In furrow in top of bed —separate operation —bedded..........	75	1,806	690	1,657	609	1,152	1,183	....	....
"Bedded on" in advance 1¾" band, 3" under seed.............	50	1,901	755	1,673	717	1,020	1,213	1,124	1,169
Band 2½" each side, 3" below seed level..	498	1,893	758	1,715	733	1,128	1,245	1,117	1,181
Mixed with soil to depth 3" under seed.	249	1,875	776	1,715	638	1,016	1,204	1,095	1,150

(1) Omitted from 1935 average because of erratic results due to an unfavorable growing season.
(2) Columbia test not conducted 1935 — stand and yield computed from previous relative standing.

same yield of seed cotton as the standard farm practice in both 1934 and 1935. These data on placement of 800 pounds of 4-8-4 fertilizer per acre indicate that the standard farm practice of applying fertilizer for cotton before bedding the land is just as good as any side placement; the choice between the two methods of applying fertilizer would depend on the cost. If more expensive machinery is required for side placement of fertilizer, the data do not indicate that a change from the standard placement is desirable.

The same yield of cotton was obtained when the fertilizer was applied on one side as when it was applied on both sides of the seed. Mixing the fertilizer with the soil had no effect on the yield of seed cotton.

Placing all of the 800 pounds of 4-8-4 fertilizer in a furrow in the top of the bed at planting time produced slightly, but not significantly, less seed cotton than the standard fertilizer placement. Applying the fertilizer in the top of the bed at planting time appears to be almost as good as applying it under the cotton 10 days before planting. This method of applying fertilizer requires one more trip through the field than where the fertilizer is applied in the water furrow before bedding the land.

In recent years a few farmers have used 6-8-4 and higher analysis fertilizers, in which all of the nitrogen is applied before or at planting. The arguments presented for the application of all of the nitrogen under the crop are that it saves the time required for side dressing, and that the additional nitrogen is bought somewhat cheaper than the extra nitrogen can be bought in nitrate of soda, which is the source of nitrogen most used for side dressing. The data on side dressing cotton with part of the nitrogen show that side dressing is profitable.

The standard farm practices of applying 4-8-6 fertilizer (7, 18) under cotton 10 days before planting and side dressing with part of the nitrogen was practically as good as any placement of 6-8-6 fertilizer at or before planting time. Where satisfactory machinery is available for planting and applying fertilizer in one operation, placing the fertilizer 3 inches to the side and 3 inches below the seed is a very satisfactory method of application, but convincing proof that farmers should go to additional expense to apply the amounts of fertilizer commonly used in this manner has not yet been presented.

Where 600 pounds of 6-8-6 fertilizer was applied per acre (Table 3), applying the fertilizer in bands 5 inches apart and 3 inches below the seed 10 days before planting cotton produced 87 pounds more seed cotton than applying the fertilizer under the row before planting, and about the same as similar methods of application on 10-day old beds at planting time. Applying 600 pounds of 6-8-6 fertilizer in a furrow in a 10-day old bed at planting time produced an average of 180 pounds of seed cotton per acre less than the standard method of application.

The application of 12 pounds of nitrogen as a side dressing in addition to 600 pounds of 4-8-6 to make a total of 600 pounds of 6-8-6 produced 134, 158, 75, 59, 4, and 121 pounds more seed cotton per acre for the different placements than 600 pounds of 6-8-6 fertilizer applied at or before planting time. Side dressing cotton with 12 pounds of nitrogen where 4-8-6 was used, instead of putting all of it under cotton as 6-8-6, increased the yield 132 pounds of seed cotton per acre

Table 3.—THE EFFECT OF METHOD OF APPLICATION OF FERTILIZER ON THE YIELD OF COTTON—600 POUNDS 6-8-6 FERTILIZER PER ACRE.

Fertilizer placement	Norfolk sandy loam N. C.[1]		Norfolk sandy loam S. C.[3]		Cecil sandy loam S. C.[3]		Cecil clay loam Ga.		Norfolk very fine sandy loam S. C.[3]	Average
	1938	1939	1938	1939	1938	1939	1938	1939	1939	
	Yield—lbs. seed cotton per acre									
	Fertilizer applied and land bedded approximately 10 days before planting									
1.75" band 3" under seed										
4-8-6[2]	1,372	1,046	386	1,066	1,431	1,882	953	1,618	2,406	1,351
6-8-6	1,288	956	338	1,137	1,193	1,581	904	1,383	2,176	1,217
Mixed with soil below seed										
4-8-6[2]	1,283	1,110	412	1,105	1,408	1,886	989	1,640	2,548	1,376
6-8-6	1,297	1,045	370	1,003	1,099	1,760	921	1,390	2,080	1,218
Bands 5" apart 3" below seed										
4-8-6[2]	1,475	1,168	406	1,248	1,381	1,883	966	1,699	2,833	1,451
6-8-6	1,463	942	397	1,137	1,315	1,957	1,045	1,665	2,459	1,376
	Land bedded approximately 10 days in advance; fertilizer applied with planting in one operation									
Bands 6" apart 4" below seed, commercial shoe										
4-8-6[2]	1,295	1,265	407	1,178	1,290	1,749	897	1,613	2,970	1,407
6-8-6	1,170	1,091	356	1,175	1,251	1,748	860	1,522	2,955	1,348
2.5" to each side, 3" below seed (B.A.E. disks)										
4-8-6[2]	1,485	943	362	1,190	1,222	1,778	794	1,558	2,900	1,359
6-8-6	1,366	1,063	357	1,195	1,089	1,793	844	1,593	2,895	1,355
In 2" band 3" under										
4-8-6[2]	1,153	864	395	1,116	1,089	1,982	953	1,562	2,828	1,327
6-8-6	1,097	794	419	885	697	1,838	956	1,425	2,657	1,196
In bands 2.5" each side on surface, pressed into soil										
4-8-6[2]		308		1,089		1,461			2,868	
6-8-6		341		936		1,486			2,439	

[1] 4%potash.
[2] Side dressed with 12 pounds of nitrogen.
Side dressed with sulphate of ammonia.

with the standard placement. The value of 132 pounds of seed cotton at 5 cents per pound is $6.60.

The cost of the additional 12 pounds of nitrogen in 600 of 6-8-6 as compared to a 4-8-6 is approximately $1.20. Its cost as nitrate of soda is approximately $1.35. The cost of nitrogen was approximately $0.15 per acre more where side dressing was used than where it was bought as additional nitrogen in the mixture.

At $6.00 per day for a man, mule, and fertilizer distributor, which should side dress 6 acres per day, the cost of applying the side dressing would be $1.00 per acre, which would make a total additional cost of $1.15 ($1.00, plus $0.15 for the extra cost of the nitrogen) per acre

to apply the side dressing. Subtracting $1.15 from $6.60 (the value of 132 pounds of seed cotton) leaves a net profit of $5.45 per acre for applying 12 pounds of the nitrogen as a side dressing, as compared to applying all of it under cotton. The cost of $1.15 per acre for applying part of the nitrogen as a side dressing can be paid by the production of 23 pounds more seed cotton per acre. In addition to increasing the yield of seed cotton by applying part of the nitrogen after cotton is up, side dressing has two other advantages which tend to offset its extra cost. They are:

1. Less grass is produced while the cotton is small when the application of part of the nitrogen is deferred until after the crop has been, worked out.
2. If for any reason a crop is lost before it is worked out, nitrogen which has been saved for side dressing may be stored until the following year, and an additional direct loss is avoided.

Data from 16 tests in South Carolina (15) show a yield of 1,006 pounds of seed cotton from 200 pounds of nitrate of soda per acre under cotton, and a yield of 1,100 pounds from 100 pounds of nitrate of soda before planting and 100 pounds as a side dressing 3 weeks after chopping the cotton. Side dressing with half of the nitrogen increased the yield 94 pounds of seed cotton per acre.

Sulphate of ammonia and forms of nitrogen other than nitrate have been called sources of nitrogen which do not leach, and it has been suggested that applying all of the nitrogen in these forms before planting is as satisfactory as applying part of the nitrogen before planting and side dressing with part of it. Laboratory experiments show that the so-called non-leaching sources of nitrogen do not leach seriously before they have been changed into the nitrate form. It takes only a few weeks to convert most of the non-leaching forms of nitrogen into nitrate nitrogen, after which they leach as readily as if they had been applied as nitrate.

Sulphate of ammonia was used as the source of nitrogen in at least 4 of the tests reported in Table 3. Where one-third of the nitrogen was applied as a side-dressing as sulphate of ammonia, 48, 248, 301, and 230 pounds more seed cotton was made than where all of it was applied before planting. In only one comparison did applying all of the nitrogen under cotton produce more cotton than side dressing with part of it with the standard placement.

That no data are available on the application of complete fertilizers after working the crop out is unfortunate. It appears that a complete

fertilizer applied 4 inches deep near the plants immediately after working the crop out would be as effective as or more effective than applying it before planting. An advantage would be found in saving fertilizer applied to crops which are lost. Also, there would be less time for phosphorus to be changed into a less available form, and for nitrogen and potash to leach out of the soil.

An attempt has been made to design one-row combination cotton planters and fertilizer distributors which apply fertilizer to the side of and below the seed at planting time. Data for one test only are available (19) using a machine of this type. Applying 500 pounds of 7-7-7 fertilizer under the cotton before planting produced a yield of 681 pounds of seed cotton per acre, and only 514 pounds was produced with machine placement at planting time (2 inches to one side and ½ inch below the seed).

Hill placement of phosphorus and mixed fertilizer for cotton has been tried out (6). Since phosphorus reacts with the soil to form less available phosphates, it appears that hill placement would increase the amount of phosphorus which plants might recover. The data shown in Table 4 have not borne out the expectations. The reason that positive results were not obtained may be due to the fact that the basic treatment was 800 pounds of 4-8-4 fertilizer per acre, which supplied 64 pounds of phosphate per acre. Probably the plants were able to get sufficient phosphorus out of 64 pounds of phosphate with band placement. It appears, though it has not been proven, that hill placement of small amounts of phosphorus might be as effective as larger amounts applied in the regular manner. If less phosphorus should be required, it would be due to maintaining the phosphorus in a more available form when it comes in contact with a small amount of soil.

Superphosphate increased the yield of seed cotton considerably more when it was placed in narrow bands or in hills than when it was mixed with the soil or applied in 8-inch bands. When soluble phosphate comes in contact with a lot of soil, the soil changes it to less available forms. Superphosphate should, therefore, be placed in narrow bands or hills and not in wide bands nor mixed with the soil.

The response of crops to nitrogenous fertilizers applied as a side dressing is determined by depth of application on dry years. The data reported on page 48 show that practically equal yields were made with both placements in some tests, and differences of as much as 300% were obtained in others. At many of the locations there was too little rain to carry the surface-applied nitrogen into the root zone. These

FERTILIZERS AND MANURES

Table 4.—Fertilizer Placement Experiment on Cotton, State College, Mississippi.

Fertilizer placement 800 lbs. 4-8-4 per acre	Yield in pounds of seed cotton per acre			
	1939	1940	1941	Average
Nitrogen from nitrate of soda— *18 percent superphosphate (356 lb./A)*				
1. NK (264 lb./A) in bands of each side P¹ mixed over 8″ width........	732	509	338	526
2. " " " P mixed over 3″ width around seed................	767	586	429	594
3. " " " P band 2½″ each side.........	826	687	359	624
4. " " " P band 2½″ one side.........	802	660	359	607
5. " " " P hill-dropped 2½″ each side...	834	611	380	608
6. " " " P hill-dropped 2½″ one side....	866	701	348	638
" " " P 1½″ band 2″ under.........	.....	582	.....	.....
Concentrated superphosphate (130 lb./A)				
7. NK (264 lb./A) in bands to each side P mixed over 8″ width........	670	631	338	546
8. " " " P mixed in 3″ width around seed.	639	566	387	531
9. " " " P band 2½″ each side.........	739	711	392	614
10. " " " P band 2½″ one side.........	608	620	386	538
11. " " " P hill-dropped 2½″ each side...	735	749	329	604
12. " " " P hill-dropped 2½″ one side....	710	679	346	578
11. " " " P 1½″ band 2″ under.........	.....	436	359	.....
(18 % superphosphate				
13. NPK (620 lb./A) hill-dropped 2½″ each side......................	710	527	343	527
14. " " 2½″ one side......................	628	417	383	476
15. " band (con't) 2½″ each side......................	757	.....	.....	.....
16. " " 2½″ each side (check)...............	658	337	305	433
Nitrogen from sulphate of ammonia no lime *(18 % superphosphate)*				
17. NPK (576 lb./A) hill-dropped 2½″ each side......................	791	465	375	543
18. " " 2½″ one side......................	772	501	349	541
19. " continuous band both sides......................	678	609	397	561
20. NK (220 lb./A) " "	688	216	262	389
Unfertilized check...	247	258	113	206

Note—All side placements 2½″ to sides, 2″ below seed level.
¹Phosphorus.

data show that nitrogenous fertilizers (as well as others) should be placed deep enough so that they are in moist soil even though dry weather follows.

The above data probably explain why unsatisfactory results have been obtained from materials used as a side dressing in some tests. Deep placement of nitrogenous fertilizers used as a side dressing rather than surface placement is more important on heavy soils than on light soils. Due to the higher water-holding capacity, more rain is required to carry nitrogen into heavy soils than is required on light soils.

Phosphorus and potash do not move out from the zone of placement to any considerable extent. In order for them to be available to plants, they must be placed deep enough to be maintained in moist soil. Relatively deep placement of these elements is of more importance in dry years. No data have been presented which show that any of the fertilizer placement tests have been conducted on soils deficient

in these elements. It appears to the author that phosphorus and potash should be applied deeper than 3 inches as was used in the tests reported above.

It appears doubtful to the author that combination planter and fertilizer distributors which place the fertilizer deep enough to maintain the phosphorus and potash in moist soil will come into use. Of greater probability is the continued use of separate machinery for planting and for application of fertilizer. This arrangement may be better adapted to the placement of fertilizer at the most advantageous depth.

The effect of placement of fertilizer upon the yield and stand of corn in North Carolina (8) is shown by the data in Table 5. The data on stand of corn show that applying 400 pounds of 4-8-4 fertilizer in the spout with the seed or one inch below delayed germination of corn.

Table 5.—STAND, COUNT, AND YIELD OF CORN ON PLACEMENT EXPERIMENT, 1937, 1938, AND 1939

No.	Treatment	Placement	1st count[1]			Aver-age	Last count[1]		Yield[2]			Aver-age
			1937	1938	1939		1937	1939	1937	1938	1939	
			Stalks on 113 feet of row						Bus. per acre			
1	400 lbs. 4-8-4	1.75" band 1" under seed...	1	99	159	86	65	154	23	17	30	23
2	400 lbs. 4-8-4	1.75" band 3" under seed...	59	177	167	134	74	167	22	14	34	23
3	400 lbs. 4-8-4	Mixed with 3" shovel lightly in row........	55	168	169	131	71	167	22	16	32	23
4	400 lbs. 4-8-4	2.5" to each side ¾" above seed....	58	180	169	136	71	168	20	12	29	20
5	400 lbs. 4-8-4	2.5" to each side 1" below seed......	36	175	164	125	68	162	22	16	36	25
6	400 lbs. 4-8-4	2.5" to each side 2" below seed.........	35	167	157	119	72	157	22	14	32	23
7	400 lbs. 4-8-4	2.5" to one side 1" below seed.........	31	181	163	125	65	158	22	13	34	23
8	400 lbs. 4-8-4	2.5" to one side 2" below seed.........	36	174	165	125	71	161	21	15	35	24
9	400 lbs. 4-8-4 plus 150 lbs. nitrate of soda	3	35	171	158	121	68	156	23	18	27	23
10	400 lbs. 4-8-4	Fertilizer in same spout with seed.....	0	62	147	104	46	150	21	13	34	23
11	150 lbs. nitrate of soda	Side-dressed when 12-18" high.........	38	174	157	123	67	158	25	14	20	20
12	None	....	40	176	159	125	61	158	17	8	7	11
13	400 lbs. 4-8-4	Corn planter shoes 1" each side seed level.	.....	.....	153	.....	.....	151	.....	.....	32	.....
14	400 lbs. 4-8-4	Corn planter shoes 2" below seed......	.....	.....	161	.....	.....	166	.....	.....	23	.....

[1] Stalks on 113 feet of row.
[2] 1937 and 1938, corn and soybeans in alternate rows; 1939, all planted to corn.
[3] 4-8-4 side-dressed when corn 6-12" high; nitrate of soda side dressed when corn 2-3 ft. high.

and that the final stand count was affected only slightly by the position the fertilizer was placed relative to the seed. The yield of corn obtained where the fertilizer was placed 3 inches under the seed was as good as any other placement, except in one case in which the difference is too small to be significant. This method of applying fertilizers is common and it appears to be satisfactory. However, the data show that there are other satisfactory placements where suitable machinery is available.

Table 6.—EFFECTS OF DIFFERENT METHODS OF FERTILIZING CORN AT WOOSTER, OHIO[1].

No.	Method of planting	Treatment (2-12-6)			Stand[2]		Height July 6	1939		1938	
		At planting May 15	June 21	July 7	I	II		Yield[5]	Inc.	Yield[5]	Inc.
		Lb.	Lb.	Lb.	%	%	In.	Bu.	Bu.	Bu.	Bu.
A	Checked	......	......	.....	100	91	59	85	....	60	....
B	Checked	150	......	.....	109	110	67	95	10	79	19
C	Checked	150	150	.....	110	104	68	93	8	79	19
D	Checked	150	......	150	109	105	68	97	12	85	25
E	Checked	150	150	150	106	99	68	100	15	85	25
F	Checked	150	150	150	106	106	66	99	14	86	25
G	Drilled	......	......	.....	100	110	61	94	....	74	....
H	Drilled	150	......	.....	90	91	66	91	—3	72	—2
I	Drilled	150	150	.....	96	97	65	97	3	71	—3
J	Drilled	150	......	150	94	95	64	92	—2	75	1
K	Drilled	150	150	150	97	101	65	96	2	89	14
L	Drilled	150	150[3]	150[4]	93	97	62	105	11	91	17

[1] Canfield silt loam; quadruplicated 2-row, 1/50 acre plots, randomized block arrangement; K-35 hybrid corn.
[2] Stand Column I, av. percent of unfertilized; Column II, av. per cent of alternate method of planting.
[3] 4-10-6.
[4] 10-6-4.
[5] 15½% moisture.

Without fertilizer, drilled corn, in Ohio, produced 9 bushels more in 1938, and 14 bushels more in 1939 than checked corn (16) (Table 6). The response to fertilizer was much greater where corn was checked than where it was drilled. The application of 150 pounds of 2-12-6 fertilizer per acre at planting increased the yield 10 bushels one year and 19 bushels the other where corn was planted in the hill, and reduced the yield insignificantly where corn was drilled. Additional applications of complete fertilizer after corn was up were effective in increasing the yield of checked corn. Fertilizing corn planted in the hill caused it to produce as much or more than corn planted in the drill.

Broadcast application of nitrogen with crop residues for increasing the yield of corn was tested at the Indiana Agricultural Experiment Station (9). It has been suggested that large amounts of nitrogen applied broadcast would help to decompose corn stalks and supply nitrogen to the growing crop. The data on broadcast application of cyanamid in Table 7 are not very encouraging for this method of

Table 7.—BROADCAST APPLICATION OF CYANAMID FOR CORN.

Pounds per acre of cyana-mid[1]	Soil type											
	Bedford silt loam		Brookston silt loam		Crosby silt loam		Parr silt loam		Miami fine sandy loam		Clermont silt loam	
	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939	1938	1939
	Yield—bushels of No. 3 corn per acre											
0	35	38	69	73	63	93	88	60	110	93	51	28
100	46	58	74	76	60	103	88	67	113	98	58	37
200	47	57	84	81	61	108	89	67	111	101	59	45
400	52	61	85	79	63	107	94	73	109	102	59	56

[1]Materials were applied on the previous crop residue and plowed under. All plots received 300 pounds per acre of 0-16-4 in the row when corn was planted.

applying nitrogen. Larger increases in the yield of corn are normally obtained for similar quantities of nitrogen applied as a side dressing.

Applying fertilizers on the plow sole or broadcast before plowing has been suggested as a means of increasing corn yields. In 12 tests where 600 pounds of 3-12-12 fertilizer was applied (17) in the row at planting time, the Indiana Agricultural Experiment Station found that 41 pounds of nitrogen plowed under increased the yield 10.4 bushels, and 20 pounds applied as a top dressing after the corn was worked out increased the yield 7.9 bushels. These data suggest that top dressing with nitrogen is more efficient than plowing it under.

The use of fertilizers in the row near the seed for corn was not effective in increasing the yield of corn in other tests in Indiana (17). It was found that it made the corn grow off more quickly and made it easier to work. The economics of this practice may not have been established.

Plowing under 82 pounds of nitrogen, 72 pounds of phosphate, and 72 pounds of potash in a total of 12 tests over a 3-year period increased the average yield of corn 16 bushels in Indiana (17). The increases varied from a decrease of 15 bushels to an increase of 46 bushels per acre.

Based on these and other available data, it appears that side dressing corn with nitrogenous fertilizers applied three to four inches deep may be the most efficient method of application.

Mixing nitrogen and phosphorus containing fertilizers with the soil reduces their efficiency. The mixing which takes place when fertilizers are broadcast on the surface of the soil and plowed under decreases the value of the fertilizer as compared to applying it in bands in the plow furrow. In Indiana (17), only 11 bushels increase in the yield of corn was obtained from 40 pounds of nitrogen broadcast and plowed under, while 17 bushels was obtained when it was applied in a band in every furrow in one test. The higher yields due to applying the nitrogen in a definite band in the plow furrow as compared to applying it broadcast were probably due to soil microorganisms tieing up nitrogen in organic matter with the broadcast application.

In two tests in Indiana (17) where the fertilizers were applied on the plow sole, phosphorus increased the yield of corn 26 bushels in one and 8 bushels in the other. Where 1000 pounds of 8-8-8 fertilizer was applied in bands on the plow sole, 14 bushels more corn was made in each test than where it was broadcast and plowed under. Mixing the phosphorus with the soil increases its conversion to unavailable forms. The Indiana Experiment Station found "where the fertilizer was placed in a band on the plow sole there was less fixation of the phosphate than where the fertilizer was broadcast and plowed under, as indicated by tissue tests and yield comparisons".

Plowing under heavy broadcast applications of fertilizer for corn production was not profitable in 43 demonstrations in Indiana in 1942 (11). The average increase in yield of corn was 6.1 bushels per acre for 500 pounds and 10.3 bushels per acre for 1000 pounds of 8-8-8 fertilizer.

Plowing under heavy applications of fertilizer was highly profitable in 4 demonstrations (11) on tobacco in Indiana. The application of 500 and 1000 pounds of 8-8-8 fertilizer increased the income $92 and $131 per acre, respectively. Tobacco has a high value per acre, and the increases in yield were relatively high. Even though the increases in money value were high, there is no evidence to indicate that plowing under fertilizers broadcast when the land is prepared is an economical way to apply them for tobacco, for no other method of application was used for comparison.

The effect of time of application of nitrogen on the yield of corn in Indiana (14) is shown by the data in Table 8. The application of 18 pounds of nitrogen per acre in the drill at planting time at North

Table 8.—Time of Application of Nitrogen to Corn in Indiana.

Ammonium sulphate plowed under[2]	Mixed fertilizer added at planting[1]	Ammonium sulphate side-dressed[2]	Location		
			North Vernon	Cloverdale	Rochester
			Bushels corn per acre[3]		
0	0	0	17	30	19
0	0-12-12	0	10	26	20
0	3-12-12	0	19	31	25
0	3-12-12	100	38	51	43
200	0	0	24	43	36
200	0-12-12	0	32	61	44
200	3-12-12	0	34	64	53
200	3-12-12	100	53	76	54
400	0	0	36	54	46
400	0-12-12	0	43	75	47
400	3-12-12	0	46	82	52
400	3-12-12	100	72	91	53

[1] 600 lb. per acre in the drill at North Vernon and Cloverdale.
400 lb. per acre in the drill at Rochester with an additional 25 pounds of potash side-dressed July 17, when the tissue tests showed that more potash was needed.
[2] The rates are in pounds per acre.
[3] No. 3 shelled corn, 17.5% moisture based on field weights.

Vernon and Cloverdale increased the yield of corn 9 and 5 bushels per acre, respectively, and 12 pounds of nitrogen at Rochester increased the yield 5 bushels per acre. In these tests the application of 20 pounds more nitrogen in 100 pounds of sulphate of ammonia as a side dressing increased the yield of corn an additional 19, 20, and 18 bushels per acre on the respective fields. It should be pointed out that the above increases in yield due to nitrogen are twice as high as are normally obtained.

In comparing side dressing with broadcast applications of nitrogen, the increases in yield over 3-12-12 fertilizer reported in Table 9 are obtained. The application of 200 or 400 pounds of sulphate of

Table 9.—Broadcast vs. Side Dressing Corn with Sulphate of Ammonia.

Amount and method of application of sulphate of ammonia	Location			
	North Vernon	Cloverdale	Rochester	Average
	Increase in yield—bushels per acre			
100 pounds side dressed...	19	20	18	19
200 pounds broadcast.....	15	33	28	26
400 pounds broadcast.....	27	51	27	35

ammonia broadcast before planting corn increased the yield of corn slightly more than did 100 pounds applied as a side dressing. On the average, 100 pounds as a side dressing produced 19 bushels of corn, and 200 and 400 pounds of sulphate of ammonia applied broadcast before planting produced 26 and 35 bushels of corn per acre, respectively. The data do not show that broadcast application of nitrogen is as effective as the usual methods of applying nitrogenous fertilizers.

Where nitrogen is applied broadcast early in the year to decompose crop residues, much of it may be tied up in the soil microorganisms, which have to be decomposed before the nitrogen becomes available again to plants. If the micro-organisms are decomposed at a time of the year when young plants are not growing, as would exist during a large part of the year in the South, much of the nitrogen

Table 10.—THE EFFECT OF FERTILIZER PLACEMENT ON THE YIELD OF POTATOES.

Location	Period	Placement of fertilizer		
		Side[1]	Band under[2]	Mixed in row[3]
		Yield—bushels of potatoes per acre		
Maine.............	4 years	392	357	349
Michigan...........	5 years	203	188	177
New Jersey.........	5 years	274	230	250
Ohio...............	4 years	238	226	225
Virginia............	4 years	248	215	228

[1] Side placement, in bands, 2 inches from, and slightly below level of seed-piece.
[2] In band, 5-6 inches wide, underneath seed-piece with an inch or two of undisturbed soil between fertilizer and seed-piece.
[3] In row, well mixed with soil.

would be lost in the drainage water. Until more data are collected the safest plan to follow is to apply nitrogen at the time needed and in a manner in which the plants can recover it quickly, which may eliminate broadcast applications of nitrogen on account of efficiency. Data from South Carolina (page 28) also show that side dressing is the most profitable way to apply nitrogen to corn.

Potatoes often receive 1500 to 2000 pounds of a high analysis fertilizer per acre. With the application of such large amounts of fertilizer, placement is important. The data (3) reported in Table 10 show that placing the fertilizer in bands 2 inches to the side of the seed piece produced considerably more potatoes than placing the fertilizer in a band under the seed or mixing it in the row. Where machinery is available for planting seed and applying fertilizer in bands before or at planting time, this method will be found to be satisfactory,

provided the fertilizer is applied deep enough to be maintained in moist soil.

The data (13) in Table 11 show that the local method of applying

*Table 11.—*PLACEMENT OF FERTILIZER FOR TOBACCO.

No.	Placement	Yield—pounds per acre				Value—dollars per acre			
		Ga.	S.C.	N.C.	Md.	Ga.	S.C.	N.C.	Md.
		1,000 lbs. 6-8-6 fertilizer per acre[1]							
1	Local method: drilled in row, mixed and ridged..............	1,363	1,693	1,583	1,050	275	358	269	208
2	Bands 2½" to side and 1" above root crown..................	1,414	1,846	1,610	1,187	279	449	264	163
3	Bands 2½" to side and 1" below root crown..................	1,464	1,824	1,665	1,140	302	423	267	238
4	2¾" band, 1" under plant........	1,006	1,438	1,382	1,202	173	247	228	202
5	Mixed with soil around plant.....	914	1,686	1,525	730	158	408	239	137
6	³/₅ at transplanting as in 3 and ²/₅ as side application.............	1,471	1,777	1,627	1,300	312	460	282	226
		500 lbs. 6-16-12 fertilizer per acre[2]							
7	Same as 1......................	1,234	1,448	1,467	1,182	249	365	259	238
8	Same as 2......................	1,338	1,561	1,410	1,087	268	374	255	197
9	Same as 3......................	1,349	1,684	1,500	1,157	281	390	269	258
10	Same as 4......................	997	1,493	936	1,220	175	275	167	190
11	Same as 5......................	892	1,765	1,354	984	147	437	238	168
12	Same as 6......................	1,361	1,664	1,442	1,402	285	414	260	275

[1]Applications in N. C. were 750 lb. per acre of 4-8-12.
[2]Applications in N. C. were 500 lb. per acre of 6-12-18.

fertilizer to tobacco can be improved upon considerably. The local method of application of fertilizer to tobacco was to drill it in the row and mix it with the soil. The yield and total value per acre was increased by placing the fertilizer on each side of the plants. Placing 3/5 of the fertilizer in bands on each side of the plants and using 2/5 as a side dressing was equal to or superior to any fertilizer placement in six out of the eight comparisons made. It appears to the author that phosphorus and potash should be placed deeper than they were in the above tests with side placement of the fertilizer.

Applying two-thirds of the nitrogen to tobacco as a side dressing increased the value of the crop $20.48 per acre in Florida (1), which is more than the cost of the fertilizer (Table 12). Since one-horse machin-

*Table 12.—*SIDE DRESSING TOBACCO.

Rate of fertilizer and method of application	Average yield per acre (lbs.)	Average selling price per 100 lbs.	Value per acre
1000 # 3-8-6 drill[1]...........	1129.63	$15.09	$170.48
1000 # 3-8-6 side dressing[2]....	1248.16	15.30	190.96

[1] All the 3-8-6 fertilizer was applied in the drill before planting.
[2] Two-thirds of the nitrogen in the 3-8-6 fertilizer was applied three weeks after transplanting.

ery is often used to prepare the land for tobacco, based upon data with cotton as well as those for tobacco, it appears that the application of all of the phosphate and half of the nitrogen and potash at planting time on one side of the list, 2 to 3 inches from where the plants are to be placed, and applying the other half of the nitrogen and potash as a side dressing would probably be the best method for farmers to use who apply fertilizer with one-horse distributors. Any fertilizer applied as a side dressing after the crop is up should be placed about 5 inches deep so that it will be in moist soil where the roots can feed on it.

FIG. 1.—Basic slag was in contact with the vetch seed on the right. The basic slag was about 2 inches below the seed on left. (Courtesy Mississippi Agricultural Experiment Station.)

Basic slag should be placed in contact with or below vetch and Austrian winter pea seed, as is shown by the data (2) from Mississippi (Table 13). Practically the same yield was obtained when basic slag was placed in contact with vetch seed as when it was placed 1 or 3 inches

Table 13.—PLACEMENT OF BASIC SLAG FOR SOYBEANS.

Plot No.	Placement of 200 lb. of basic slag per acre	Yield of air-dry vetch— pounds per acre
1	No basic slag.....................	1,100
2	Contact with seed.................	2,264
3	1″ below seed....................	2,108
4	3″ below seed....................	2,153
5	1″ to side of seed, 1″ below.........	1,848
6	2″ to side of seed, 1″ below.........	1,940
7	3″ to side of seed, 1″ below.........	1,617
8	4″ to side of seed, 1″ below.........	1,645

below the seed. Any side placement of basic slag resulted in a reduction in yield. The above data were obtained on a sandy loam soil. The writer has observed that it is necessary to place basic slag in contact with vetch seed on heavy soils (Figure 1).

Superphosphate or a mixture of superphosphate and dolomite should not be placed in contact (2) with legume seed (Table 14). These fertilizers should not be placed immediately below the seed at planting time; they should be placed to the side of and well below the seed. Muriate of potash was very harmful when as little as 50

Table 14.—The Effect of Fertilizer Placement on the Yield of Austrian Winter Peas.

Plot No.	Placement of 200 lbs. superphosphate and 200 lbs. dolomite per acre relative to seed	Yield of air-dry Austrian winter peas—pounds per acre
1	1 in. below	1,440
2	3 in. below	1,244
3	2 in. below 2 in. side	1,767
4	2 in. below 3 in. side	1,943
5	2 in. below 4 in. side	1,398
x	No fertilizer	674
6	1 in. below 2 in. side	1,807
7	3 in. below 2 in. side	1,802
8	Mixed with soil to a depth of 3 in. below	1,471
9	Contact	1,089
10	Contact plus 50 lb. muriate	745
11	Contact plus 100 lb. muriate	644
12	Contact plus 200 lb. muriate	475
x	No fertilizer or inoculation	76
13	Super contact, dolomite 2 in. below, 2 in. side	1,052
14	Dolomite contact, super 2 in. side, 2 in. below	2,189
15	Super one side, dolomite other side, 2 in. side, 2 in. below	2,084

pounds per acre was placed in contact with the seed. The data reported are for Austrian winter peas; similar results were obtained with soybeans. Where fertilizers and seed are to be broadcast there probably will not be enough fertilizer near the seed to produce any injurious results if they are applied together.

The application of nitrogen as ammonia in irrigation water has been investigated (5). The loss of nitrogen applied in irrigation water as ammonia increased as the length of time required for the water to go into the soil increased, and as motion of the water increased (Table 15). With nitrogen applied as ammonia in irrigation water a considerable amount of it would be fixed in the surface, which may not be available to plants in dry weather; and, under alkaline conditions,

Table 15.—LOSSES OF NITROGEN APPLIED AS AMMONIA IN IRRIGATION WATER—50 POUNDS OF NITROGEN PER *1,000,000* pounds of water.

Time for water to go into soil hours	Percent of nitrogen lost	
	Solution still	Solution in rapid motion
0.24	0.7	1.5
0.50	1.4	3.3
1.00	2.9	6.6
2.00	5.8	13.2
4.00	10.6	26.4

which are general in irrigated sections, a considerable part of the ammonia may be lost into the air. It appears that other means of applying nitrogen to alkaline irrigated soils may be more desirable than the application of ammonia in irrigation water.

Considerable nitrogen may be lost into the air when ammonia sources of nitrogen, like sulphate of ammonia, are applied on the surface of alkaline soils (12):

Soil No.	pH	Percent of nitrogen lost into air
1	7.0	0
2	8.6	13
3	9.3	13
4	10.5	87

When the pH of the soil was above 7.0 the loss of nitrogen as ammonia into the air was considerable. Calcium nitrate has been superior to sulphate of ammonia for surface application, and deep application of sulphate of ammonia has been superior to surface applications on alkaline irrigated soils.

SUMMARY AND CONCLUSIONS

An examination of a great deal of information on fertilizer placement leads to the following general conclusions:

1. Low-analysis fertilizer at low rates per acre may be applied to cotton with the seed, or in any convenient position near the seed with satisfactory results.
2. Up to 800 pounds of low-analysis fertilizers may be applied in a band 3″ below the seed 10 days before planting satisfactorily, but at planting time it should be applied 2 to 3″ to one side and 2 to 3″ below the seed.

3. When large amounts of fertilizer are applied, they should be placed to the side of the seed and about 3 inches below.
4. One band is just as good as two up to 600 to 800 pounds per acre. With higher rates, two bands may be more desirable.
5. Where farmers are using relatively low amounts of fertilizer and applying part of the nitrogen as a side dressing, the methods of application which they have become accustomed to are probably satisfactory in most cases.
6. Where side placement of fertilizer is desirable, the fertilizer may be applied on one side of the list with ordinary machinery or placed accurately at planting time with special machinery.
7. Superphosphate should be applied in narrow bands near the seed. It should not be mixed with the soil nor applied in wide bands for cultivated crops.
8. Basic slag should be placed in contact with or below legume seed.
9. Lime may be placed in contact with any seed.
10. Superphosphate and muriate of potash should not be placed in contact with legume seed.
11. Nitrogenous or other fertilizers should be placed about 4 inches deep when used as a side dressing.

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Returning the Nitrogen, Phosphorus, and Potash Harvested in Crops to the Soil in Manure

Manure is high in potash.

The value of farmyard manure depends upon the feed animals receive. Feeds high in nitrogen, phosphorus, and potash produce manure which is high in these elements. The percentage of the fertilizing elements recovered from the feed given to steers in Ohio (1)[1] was as follows:

	Percent recovered		
	Nitrogen	*Phosphorus*	*Potash*
Concrete floors...........	75	78	88
Earth floors.............	62	78	78

The nitrogen and potash lost from manure is in a readily available form. The increased value of the manure obtained from fattening steers on concrete floors was calculated to be sufficient to pay for the floors in two six-months feeding periods. The value of farmyard manure is generally recognized. Salter and Schollenberger (10, 11) estimated that the average income per ton of manure applied to crops is $2.50. If fertilizers produce crops equal to three times their cost, the fertilizing value of one ton of manure applied to the land becomes about $0.85. The value of the crop produced per ton of manure varies widely, depending upon the manure used, and the value of the crop grown.

The plant food content of manure varies so widely that little reliability can be placed in experimental work reported on its use unless the nitrogen, phosphate, and potash contained are reported.

[1]Numbers in parenthesis refer to the source of information, page 403.

If the nitrogen, phosphate, and potash content of the manure used in experimental work were reported, the data would still be difficult to use because the composition of the available farm manure is unknown. The following data on mixed horse and cow manure from Canada were reported in an Ohio bulletin (10):

Fertilizing element	Treatment of manure		
	Fresh	Rotted for six months	
		Protected	Exposed
	Pounds per ton		
Nitrogen...............	12	34	16
Phosphate.............	6	22	11
Potash................	15	51	21

The manure which was rotted for six months where it was protected (stored in a shed) contained approximately 3 times as much nitrogen, phosphorus, and potash as fresh manure. The increase in these elements on rotting manure is due to a reduction in the water content, and to partial decomposition of the organic matter, which increase the percentage of nitrogen, phosphate, and potash in the manure.

In the Southeast manure is usually applied only in the spring of the year. In many sections of the country manure is stored in one manner or another through the winter months. Manure which is properly stored for six months or longer may be expected to have 30 to 40 pounds of nitrogen, 15 to 25 pounds of phosphate, and 30 to 50 pounds of potash per ton. If 10 tons of rotted manure is applied per acre, the soil may receive 300 pounds of nitrogen, 150 pounds of phosphate and 300 pounds of potash. The fertilizers required to supply these amounts of plant nutrients would be 1,875 pounds of nitrate of soda, 750 pounds of 20% superphosphate, and 500 pounds of 60% muriate of potash. The reasons for the unusually good effects of manure and the effects on the following years are evident.

The nitrogen, phosphate, and potash in a ton of fresh manure produced by different animals (10, 14) are reported in Table 1. As was pointed out above, the analysis of manures depends upon the feed the animals receive. Hen manure is more valuable than other manure because hens eat feed which is higher in nitrogen, phosphorus, and potash; and it has a relatively low water content. Most of the manure saved on farms is cow manure.

One ton of fresh solid cow manure contains 6 pounds of nitrogen, 4 pounds of phosphate, and 3 pounds of potash. Due to the low value of nitrogen in fresh manure for crop production (10), in comparison to nitrogen in commercial fertilizer, only 2 pounds of nitrogen in a ton of solid cow manure can be counted. On the basis of the present

Table 1.—THE NITROGEN, PHOSPHATE, AND POTASH CONTENT OF ONE TON OF MANURE.

Animal	*Dry matter*	*Nitrogen*	*Phosphate*	*Potash*
	Solid, lbs. per ton			
Horses.............	486	10	6	4.8
Cattle.............	322	6.4	4.2	3.2
Sheep.............	690	13.0	9.2	4.6
Hogs..............	360	12.0	9.2	8.8
Hens (1)...........	900	20.0	16.0	8.0
	Liquid, lbs. per ton			
Horses.............	198	24	Trace	30
Cattle.............	124	19	.6	19
Sheep.............	256	33.6	.6	42
Hogs..............	66	6	2.4	20

prices of fertilizers, the value of one ton of fresh solid cow manure is calculated as follows:

```
2 pounds of nitrogen at 10 cents per pound.................. $0.20
4 pounds of phosphate at 5 cents per pound................  0.20
3 pounds of potash at 4 cents per pound...................  0.12
                                                           ─────
   Total value of one ton of fresh cow manure............ $0.52
```

If one-fifth of the water in the manure evaporates, the value of the manure increases to $1.04 per ton. If three-fifths of the water evaporates, the value increases to $2.08 per ton. If the moisture is reduced to 40% and half of the organic matter rots its value could increase to $8.32 per ton.

The value of one ton of liquid cow manure was calculated as follows:

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19 pounds of nitrogen at 10 cents per pound................ $1.90
0.6 pounds of phosphate at 5 cents per pound..............  0.03
19 pounds of potash at 4 cents per pound..................  0.76
                                                           ─────
   Total value of one ton of liquid manure................ $2.69
```

One ton of liquid manure is worth four times as much as one ton of

fresh solid cow manure. A cow producing one ton of solid manure worth $.52 produces 768 pounds of liquid worth $1.03.

The distribution of the fertilizing elements between the liquid and solid manure is important in determining the disposition to be made of the manure. The values of the fertilizing elements are as follows:

| | Weight produced | |
| Value of | 2,000 pounds | 768 pounds |
	Solid	Liquid
Nitrogen.........................	$0.20	$0.71
Phosphate	0.20	0.01
Potash...........................	0.12	0.29
Total.....................	$0.52	$1.01

The solid manure contains $0.32 worth of phosphate and potash to $0.30 contained in the liquid. If the liquid manure and part of the solid manure are lost, as is often the case with dairy cattle, somewhat less than $0.32 worth of phosphate and potash gets back to the soil; if it all is permitted to fall on the pasture or hay land, $0.70 worth of phosphate and potash is returned to the land. The nitrogen in the urine which falls on growing pastures should be available for use by the grasses.

The generally accepted plant nutrient content of fresh manure containing both liquid and solid and bedding is 10 pounds of nitrogen, 5 pounds of phosphate and 10 pounds of potash per ton. On account of the low value of the nitrogen, Salter and Schollenberger (10, 11) concluded that a ton of stable manure is equal to 100 pounds of 3-5-10 or 4-5-10 fertilizer. The fertilizer value of one ton of average fresh manure, containing both solid and liquid, was calculated as follows:

4 pounds of nitrogen at 10 cents per pound.................. $0.40
5 pounds of phosphate at 5 cents per pound................ 0.25
10 pounds of potash at 4 cents per pound.................. 0.40

Total value.. $1.05

Where legumes are grown in rotation, stable manure is considered to be low in phosphorus, and supplementing stable manure with superphosphate has proven profitable. For crops like cotton, which are not grown in rotation with legumes, stable manure is low in both nitrogen and phosphate, or it is high in potash. Since stable manure is usually applied at high rates per acre, the nitrogen and phosphate

should be satisfactory for cotton or corn, and the excess of potash should reduce the potash requirement on the following years.

The loss of nitrogen and potash in untreated manure in shallow piles (10 inches deep) in the open for 3 months was very high (Ohio) (1):

Nitrogen	36% lost
Potash	51% lost
Phosphate	22% lost

The manure from the barn increased the value of the crops produced $3.73 per ton and that stored in the open in shallow piles for 3 months increased the value of the crops produced $2.93 per ton of manure. The loss in deeper piles would be less, and the loss in warmer climates would be greater.

Manure decomposes in storage (8), and the total amount of manure present is reduced (England):

Treatment of manure	Loss in dry weight		Loss in nitrogen	
	In open	In shed	In open	In shed
	Percent	Percent	Percent	Percent
Compact 3 months	39	30	28	26
Compact 9 months	60	48	50	42
Loose 3 months	41	35	27	26
Loose 9 months	60	45	51	32

The loss in dry weight of manure was one-third greater in the open than in a shed. The loss of nitrogen was almost as great as the loss of dry weight.

The manure stored in the shed had a much higher fertilizer value than that stored in the open (8) when applied to crops at the rate of 10 tons per acre:

Manure treatment, rate per acre	Yield of potatoes, tons per acre	Yield of wheat, pounds per acre
Months manure was stored	3	9
No manure	5.11	4,943
10 tons compact in shed	9.00	5,792
10 tons compact in open	7.38	5,364
10 tons loose in shed	8.82	5,649
10 tons loose in open	8.02	5,185

The manure stored in the shed lost less dry weight and less nitrogen, and, with 10-ton applications, produced considerably more potatoes and wheat. Compacting manure in the shed increased its value, and in the open compacting reduced its value.

Table 2.—THE EFFECT OF TREATMENT OF MANURE ON THE AVAILABILITY OF THE FERTILIZING ELEMENTS TO CROPS.

Treatment of manure	Tons per acre	Pounds nitrogen per acre	Pounds nitrate nitrogen in soil (fallow) per acre				Yield of barley lbs.
			20 days	35 days	50 days	65 days	
1. Check......................	......	....	9	18	18	19	1,118
2. Rotted[1], plowed under at once.....................	11.8	137	15	68	103	138	4,461
3. Rotted[1], received ½ inch rain, dried for 15 hours before turning..............	11.7	135	20	66	61	81	3,660
4. Rotted[1], dried 15 hours before turning.............	11.5	133	17	62	48	65	3,615
5. Rotted[1], disked in surface at once.....................	11.3	131	18	89	121	115	4,351
8. Fresh urine only, plowed under at once...........	0.2	62	81	71	70	71	3,418
9. Fresh solid only, plowed under at once.............	8.3	59	8	12	12	21	822
10. Fresh, solid and liquid, plowed under at once.....	11.3	125	33	42	29	149	3,926
11. Fresh, solid, liquid and straw[2], plowed under at once.....	11.5	142	17	52	53	79	3,642
12. Fresh, solid, liquid and straw[2], dried 15 hours before turning.....................	11.6	144	25	29	38	61	3,082
13. Fresh, solid, liquid and straw[2], rotted 3 days and dried 15 hours before turning......	11.8	152	23	21	43	68	2,479
6. Artificial, from grain straw rotted for 18 months, plowed under at once.....	11.2	136	6	10	15	23	1,101
7. Artificial, from grain straw plus sulphate of ammonia, rotted for 18 months, and turned under at once......	10.6	171	7	9	15	43	1,124

[1] Rotted for six weeks.
[2] Straw equal to 6% of the weight of the manure was used.

The value of manure depends upon the kind of manure and its treatment (4) (Table 2). Rotting manure, containing both the liquid and solid, for six weeks increased its value slightly. The value of rotted manure was decreased about 25% by drying; drying fresh manure containing both the liquid and solid decreased its value about two-thirds. The decrease in value of the manure produced by drying was

due to the loss of ammonia nitrogen into the air. In Vermont (6), it was found that 93% of the ammonia nitrogen was lost when manure was thoroughly dried.

Fresh manure containing both the liquid and solid, and straw, which was stored for 3 days and dried after applying, lost nearly half of its fertilizing value. The fresh solid manure had no value for fertilizer during the 65 day growing period of the test. The liquid alone produced almost as much barley as the fresh solid and liquid. It appears that nearly all of the crop producing power of fresh manure is in the liquid. The liquid is quite often lost.

Artificial manure made from grain straw or straw and sulphate of ammonia over an 18 months period had no value as fertilizer.

The production of nitrates where the manure was applied to fallow land was in proportion to the increase in crop yield.

The potash in stable manure is water soluble, and it is just as available as that in commercial fertilizers.

The phosphorus in stable manure is probably more available for field crops than that in fertilizers, due to its being enclosed in organic matter, which protects it from the mineral soil, and, as a result, it stays available longer than that in mineral fertilizers.

The phosphorus in stable manures penetrates into pasture soils to a much greater extent than does phosphorus in fertilizers (3). Due to the loss of nitrogen into the air from manure applied to pastures, and the use of legumes to supply nitrogen to pasture grasses, manure which has accumulated at the barn may be used more profitably on cultivated crops which require nitrogen than on pastures.

The value of the straw and the labor involved in saving liquid manure may be greater than the cost of buying the same amount of nitrogen and potash in commercial fertilizers, except where the value of the straw is obtained as bedding. The liquid manure is usually lost with dairy cows which are not bedded down in the barn. Where dairy cows are bedded down, much of the liquid may be absorbed in the bedding material. With maximum absorption of liquid by straw, it takes approximately 1000 pounds of straw to absorb a ton of liquid manure (10, 11). The ton of liquid manure is worth $2.69 (see above).

The liquid manure from dairy barns may be saved by running it into tanks, from which it is hauled directly to the fields. This system is used in the intensive dairy sections of Europe. The practice of saving liquid manure as such originated while the price of nitrogen and potash was very much higher than at present. The initial cost of building tanks for holding the liquid is high. Also concrete floors in

the barns are necessary for recovery of the liquid. With the present costs of labor and equipment, and the present low cost of nitrogen and potash, it is doubtful if the storage and application of liquid manure as such is an economical practice.

An oil layer $\frac{1}{4}$ inch deep conserved almost all of the nitrogen in liquid manure (Wisconsin) (5):

	Percentage of nitrogen lost
No treatment......................	26
Superphosphate.....................	14
Layer of oil.......................	1

Oil was much more effective than superphosphate for conserving the nitrogen in liquid manure. The oil keeps air out and prevents the nitrogen from being converted into ammonia, which is easily lost into the air.

A satisfactory system for saving manure is to pen the cows in a shed. The liquid and solid are deposited together. The high moisture content of the mixture combined with the packing of the cattle tend to prevent decomposition and conserve the nitrogen. This system is particularly adapted to fattening beef animals.

If a successful livestock system of farming is to be maintained, the phosphorus and potash removed in the harvested feed must be returned (see Chapter 8) to the land from which it came. It appears from the data available that much more phosphorus will have to be added to the soil than is recovered in the crops. Even under a good system of handling manure, considerable amounts of the plant nutrients are lost. The cost of handling manure is quite high, and it probably approaches the cost of commercial fertilizers of equal crop-producing value. The fertility of the soil may be maintained more easily, and probably more economically, where manure falls directly on the land on which the hay crops are produced. Where pasture land and hay land can be rotated successfully, and manure from feed falls on pasture land, the fertilizing elements can be distributed rather uniformly over the farm.

In the Southeast the cost of developing a good pasture does not permit pasture land to be rotated with cultivated crops. However, in many cases at least, pasture land produces as much or more hay than cultivated hay land. Hay may be produced on pastures without annual seeding or land preparation. Also, the seasonal distribution of the

growth of pasture grasses is much wider, thus increasing the possibility of obtaining greater yields of hay or silage from land in pasture than from land in cultivated crops. If the cost of preparing land and seeding hay crops were added to pastures as fertilizer, and if hay were obtained directly from pastures, much higher yields of both hay and pasture might be maintained. Cattle which are fed fairly well do not necessarily need a shed in the winter in the Southeast. Feeding hay from stacks on the pasture will help to prevent the depletion of phosphorus and potash which normally takes place on hay land.

The Woburn (England) Experiment Station conducted a number of experiments on the effect of feeding cottonseed cake and corn on the yield of the crops which followed (9). With cattle fed cottonseed cake supplying nitrogen equal to 200 pounds of nitrate of soda more than cattle fed corn, the plots on which cake was fed produced only one to two bushels more barley per acre than where corn was fed. The failure of the extra nitrogen in the cake to increase the yield of the following crop was probably due to its loss into the air and to leaching before the grain crop could utilize it.

Superphosphate has been recommended for conserving the ammonia nitrogen in stable manure (6). Superphosphate conserves ammonia nitrogen by forming sulphate of ammonia and more insoluble phosphate. In ordinary manure the change in the form of phosphate is small, but in urine superphosphate may take up sufficient ammonia to convert phosphorus into tricalcium phosphate (calculations made on Vermont data) (6), which, in the presence of the calcium fluoride in the superphosphate, may be converted into new rock phosphate. The new rock phosphate has a low value for fertilizer. However, the Wisconsin Experiment Station (5) found that the use of 138 pounds of 45% superphosphate per ton of urine saved less than 3 pounds of nitrogen during a period of one month. The urine lost nearly 4 pounds of nitrogen per ton even with superphosphate treatment. If urine were stored in tanks, the removal of the phosphate from the bottom of the tank would make its use impractical.

Where manure was kept moist, 80 pounds of superphosphate per ton of solid manure saved less than one pound of nitrogen (6). Where 80 pounds of superphosphate was used with one ton of liquid and solid, the saving was less than 2 pounds of nitrogen. The manure used in the Vermont Experiments had 5 pounds of ammonia nitrogen per ton. The ammonia nitrogen was reduced to 0.4 pounds per ton on completely drying the manure. When 100 pounds of superphosphate was partially mixed with one ton of manure and the manure was dried, 0.7 pounds

of nitrogen was saved. The data obtained where the superphosphate was partially mixed is probably comparable to what a farmer using superphosphate on manure would do. When the manure received extra water and the superphosphate was thoroughly mixed with one ton of manure, 2.4 pounds of ammonia nitrogen was saved when the manure was dried.

From the standpoint of the ammonia nitrogen saved when super-phosphate was mixed with solid manure or a combination of solid and liquid manure, none of the data reported show a saving of sufficient nitrogen to pay for the labor involved.

The application of 50 pounds of superphosphate per ton of fresh manure is the equivalent of approximately 100 pounds per ton of manure applied to the field after partial decomposition and the loss of a small amount of moisture. An application of 8 tons per acre of rotted manure carrying 100 pounds of superphosphate per ton would carry 800 pounds of superphosphate, which is much more than is normally used. Since stable manure is normally broadcast, the super-phosphate would be broadcast also. Small amounts of superphosphate applied near the seed have proven to be better than larger amounts broadcast. It, therefore, appears that superphosphate should be applied separately and not with manure. Reinforcement of stable manure with superphosphate does not appear to be a satisfactory way to use superphosphate.

The use of nitrogen with stable manure was slightly more profitable than the use of superphosphate as shown by data from 33 experiments in Washington (2) on a variety of crops including oats, barley, corn, mixed grasses, red clover, alfalfa, sugar beets, and potatoes:

Treatment per acre	Relative yield
None	100
Manure[1]	124
Manure plus nitrogen[2]	146
Manure plus phosphate[3]	140
Manure plus nitrogen and phosphate	155

[1] 5 or 6 tons of manure per acre.
[2] 75 or 90 pounds of sulphate of ammonia per acre.
[3] 100 pounds of 45 % superphosphate.

The above data show that nitrogen was just as effective or more effective than superphosphate when used with 5 or 6 tons of stable manure per acre. The need for nitrogen or phosphate with manure apparently depends upon the rate at which manure is applied, and on the supplies of these elements in the soil. In the above experiments

5 or 6 tons of manure was applied per acre, which may be much less than most farmers apply.

Manure applied in the drill at the rate of 5 tons per acre increased the yield of seed cotton 82 pounds per acre more than did broadcast applications (12) in South Carolina. The data reported were from several farms, and drilled application was more effective than broadcast application in every case.

Four tons of manure applied in the drill for cotton (7) was as effective as 8 tons broadcast (Mississippi). The drilled manure made 172 and 113 pounds of seed cotton per acre more than the broadcast manure at the 4 and 8 ton rate, respectively.

SUMMARY AND CONCLUSIONS

The data reviewed in this chapter show that:

1. The loss of nitrogen in wet solid manure stored for 3 months is negligible. The loss of nitrogen from liquid manure is high. The loss of nitrogen from a mixture of liquid and solid manure is approximately 40% when stored for three months.
2. Almost all of the readily available nitrogen in stable manure was lost when it was air dried.
3. The saving of ammonia nitrogen, due to the application of superphosphate to mixed solid and liquid manure, or liquid manure, is too small to justify the cost of mixing the superphosphate and the manure, or removing the superphosphate from storage tanks.
4. Manure should be maintained wet in storage, preferably under cattle, and applied to the land on a cloudy day and covered immediately.
5. Production of hay on pasture land, and permitting cattle to drop the manure on the land is a practice which will reduce the loss of phosphorus and potash in livestock farming.

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(18)

Fertilizing Ponds for Fish Production

Well fertilized ponds produce 600 pounds of fish per acre.

The most commonly used bait for bass is minnows or other small fish. Small fish are good bait for bass because they live almost entirely on small fish after they have reached a few inches in length. Small bass and blue gill bream eat water insects. Ninety-five per cent of the food eaten by bream was found to be water insects in Alabama (8)[1]. Bream which are so small that it takes 500 to weigh a pound, live on the same food as larger bream (8).

Approximately 50% of the legal-size fish can be removed by fishing (9). Where artificial bait is used the first one or two fish caught may be cut open to determine what they are eating, which will aid in the selection of lures. For pole fishing the best bait for bass is minnows, or other small fish; however, they will occasionally bite earthworms, catalpa worms, crickets, grasshoppers, crawfish, or frogs. Earthworms are good bait for bream during most of the year, except in the late summer and fall when wasp grubs and crickets are better. Catalpa worms, corn ear worms, cotton leaf worms, cutworms, grasshoppers, and cockroaches are good bait for bream. Bream are usually more easily caught when the baited hook without a sinker is placed on the bottom of the pond.

The insects which supply food for the small fish live on small water plants called plankton. These plants are so small that they can not be seen without the use of a microscope. The presence of the small water plants is recognized by the color of the water. Clear water is free of these plants; green water has an abundance of them which are growing; brown water contains the small plants, but they are not growing and multiplying. These plants require sunlight and fertilizers for growth, just like corn and cotton.

The effect of fertilizers on the production of microscopic water plants and fish is shown by the data (6) in Table 1 from Alabama

[1]Numbers in parenthesis refer to the source of information, page 417.

The data were collected between September 9 and May 1. In the well fertilized ponds 251 and 330 pounds of fish were produced. The production of fish was usually proportional to the amount of microscopic plants found in the water. The data on the production of water plants would be similar to records taken on the production of grass in a pasture where cattle are grazing. The weight of grass in the pasture or the weight of plankton found does not indicate the amount which has been consumed. Water plants furnish a continuous supply of food for insects, and no great amount of plants occur in the water at any one time.

Table 1.—THE EFFECT OF FERTILIZERS ON THE PRODUCTION OF BOTH MICROSCOPIC WATER PLANTS AND FISH.

Pond No.	Treatment	Pounds per acre[1]	
		Microscopic water plants	Fish
1	None..	39	90
2	Superphosphate................................	29	134
3	Superphosphate and nitrate of soda.............	53	156
4	Superphosphate and sulphate of ammonia........	96	174
5	Superphosphate, nitrate of soda and muriate of potash......................................	65	251
6	Superphosphate, nitrate of soda, muriate of potash and lime....................................	199	330
7	Nitrate of soda................................	37	79

[1] 3 feet deep.

The high acidity (pH 4.0 to 4.7) where sulphate of ammonia was used apparently prevented the growth of sufficient insects to utilize the microscopic water plants produced as completely as they were utilized in other ponds. Even with the excessive acidity produced with the use of sulphate of ammonia, it was slightly superior to nitrate of soda as the source of nitrogen for production of both water plants and fish where potash was not used.

The above data on the production of microscopic water plants and fish are comparable to data on field crops in the following respects:

1. Nitrogen is required.
2. Phosphorus is required.
3. Potash is required.
4. Lime is required.
5. The use of sulphate of ammonia without lime increases acidity.

The fertilizers recommended for fishing ponds by the Alabama Agricultural Experiment Station (2, 7) per acre of water are as follows:

40 pounds of sulphate of ammonia	or 100 pounds of neutral 6-8-4
60 pounds of superphosphate (16%)	10 pounds of nitrate of soda.
5 pounds of muriate of potash	
30 pounds of basic slag or 15 pounds of lime.	

The following fertilizers will supply about the same amount of plant nutrients, and they should be satisfactory:

50 pounds of nitrate of soda	or 100 pounds of neutral 4-8-4
60 pounds of superphosphate	25 pounds of nitrate of soda.
5 pounds of muriate of potash	
30 pounds of basic slag or 15 pounds of lime.	

Two to three applications of one of the above fertilizer mixtures should be made at weekly intervals in March, and at intervals of four weeks thereafter until October. After the weekly fertilizer applications have been made in the early spring, the other applications may be withheld until the growth of water plants slows up, which is indicated by the water getting clear. When the water becomes clear enough for the bottom of the pond to be seen through $1\frac{1}{2}$ to 2 feet of water, fertilizer is needed. The water will lose its green or brown color and become clear every four to six weeks, at which time fertilizers should be applied.

Pond "moss" or "grass" which grows under the water from the bottom of the pond can be controlled by fertilizer (9). The fertilizers used to control moss are the same as those listed above to increase the production of fish. For moss control, the application of fertilizer is started in December or January. The fertilizer should be broadcast over the entire pond, where under-water moss is present. The fertilizers are applied every two to four weeks until algae cover the underwater plants. The algae shade these plants, and they break off near the bottom, and the pond becomes covered with decaying scum. Fertilization should be discontinued while the moss is decaying rapidly, because fertilizer increases the rate of decomposition, which increases the carbon dioxide in the water; carbon dioxide kills fish when present in too large quantities. The decaying moss should furnish sufficient fertilizer for the rest of the year or until such time as the bottom of the pond can be seen through $1\frac{1}{2}$ to 2 feet of water.

The fertilizers may be thrown into the water from the edge of small ponds or from boats in larger ponds. It is not necessary to distribute the fertilizer uniformly because the wave action of the water will distribute it sufficiently. A total of 10 to 14 applications of fertilizer costing $10 to $15 per acre should be made during the year.

FIG. 1.—Method of application of fertilizers to
ponds (2). (Courtesy Alabama Agricultural
Experiment Station.)

A one-acre pond was stocked in 1936 and fertilized by the Alabama
Agricultural Experiment Station (4). The fertilizer cost $10 per acre
in 1936 and 1937, and $15 in 1938. The pond was fished lightly each
year by several families. The fish caught in 1938 were as follows:

Kind of fish	Number	Weight—Pounds
Large mouth black bass...................	14	25
Blue gill bream..........................	164	45
Yellow bullhead.........................	11	7
Total.............................	xxx	77

The pond was drained in January 1939, and the fish removed were as
shown in Table 2. With heavier fishing most of the legal size fish could
have been removed. The pond contained sufficient small bream to
stock a 5-acre pond and sufficient small bass to stock a 1.3 acre pond.
There were 135 pounds of shiners, which should be replaced by bream.

A 1.3 acre pond was stocked in February 1939 by the Alabama
Agricultural Experiment Station (8). It was fertilized, and by the
following December it contained 1663 legal-size bream, and 90 legal-
size bass. The pond produced 479 pounds of fish per acre in 10 months,
and 392 pounds were legal size. Normally 500 to 600 pounds of fish
per acre are produced in well fertilized ponds and 100 to 200 pounds
in unfertilized ponds in Alabama.

The maximum production of fish would be obtained from ponds
which are fished heavily, and drained annually to remove the fish of

legal size. No data are available on the quantity of fish which can be removed by fishing heavily; however, on the basis of catching 50% of the legal size fish it appears that 200 to 300 pounds per acre might be caught from well fertilized and stocked ponds, and 50 to 75 pounds per acre from unfertilized well stocked ponds. From the standpoint of sport, the increase in production of fish is easily worth the money; from the standpoint of cost of meat, the fish produced through the addition of fertilizer would cost 4 to 7 cents per pound of fish caught where the pond is fished heavily.

Table 2.—THE PRODUCTION OF FISH BY A FERTILIZED POND IN ALABAMA.

Kind of fish	*Number*	*Weight—pounds*
Golden shiners...........................	2353	135
Small bream[1]..........................	7880	174
Large bream..........................	263	65
Small bass[2]...........................	346	77
Large bass............................	76	124
Yellow bullhead.......................	8	5
Top water minnows....................	222	...
Total legal fish..................	xxxx	194
Total fish removed by fishing........	xxxx	00
Total legal fish..................	xxxx	271

[1]Under 5 inches in length.
[2]Under 11 inches in length.

The cost of fertilizing a one-acre pond in Alabama (4) was $10 per acre in 1936, and in 1937. In 1938 the cost was $15. The higher cost in 1938 was due to an excessive amount of rain which flushed the fertilized water out of the pond. Where ponds are filled by springs or rains are constantly flushing the fertilizer out, the cost of maintaining the fertilizer content of the water is high.

Ponds preferably should not be permitted to overflow where they are to be fertilized because the overflow water carries valuable plant nutrients with it. It is not always practicable to prevent ponds from overflowing. The construction of terraces around small ponds reduces overflow to a minimum. The spillways of the pond should be through the terrace outlets. The terrace outlets should be at the high-water level of the pond, and they should be wide enough so that the water spreads out in them and does not rise significantly during heavy rains. The terrace outlet should be connected to the pond by a narrow channel. The terraces should be laid off from the outlets giving them a

fall of 3 inches per 100 feet, or a graded fall. If a pond is terraced in this manner the water will run into the pond when the water level is low and around the pond when it is full. The terraces will reduce the amount of sediment which goes into the pond, and the life of the pond should be increased.

STOCKING PONDS

Often ponds stocked with fingerlings become crowded with very small fish, and few, if any, legal-size fish are produced. The trouble is that the balance was not maintained between fish which eat insects and fish which eat small fish.

The Alabama recommendations for stocking ponds (8) are:

1. Unfertilized ponds which will support 150 pounds of fish per acre,
      400 fingerling blue gill bream,
        30 fingerling large mouth black bass,
          top water minnows.
2. Fertilized pools which will support 600 pounds of fish per acre,
      1500 fingerling blue gill bream,
       100 fingerling large mouth black bass,
         top water minnows.

Where crappie (white perch) are desired, they may be used in place of bass up to one-fourth of the bass; one fingerling cat may be used for 4 bream up to 25% of the bream. Catfish do not thrive in most ponds where bass are present. Minnows are put in to control mosquitoes.

When a well fertilized pond was stocked in February 1939 with blue gill bream and bass as recommended above (8) in December, the pond contained the numbers and weights of fish per acre reported in Table 3.

*Table 3.—*The Production of Fish in a Well Fertilized Pond.

Kind of fish	Number	Weight—pounds
Blue gill bream—large	1,279	333
Blue gill bream—small	6,320	38
Large mouth bass—large	69	55
Large mouth bass—small	148	22
Crappie—large	3	3
Crappie—small	185	28
Top water minnows	159	...
Total	xxxx	479
Total legal-sized fish	xxxx	392

In addition to the above fish, 31 bream and 4 bass had been removed previously. The bass kept the number of bream reduced and the smaller number of fish present permitted 82% of the total weight of the fish to grow to catching size.

Stocking a moderately fertilized pond with blue gill bream only at the rate of 1,500 per acre in March 1939 gave unsatisfactory results (8). The size of the bream is shown by the following data:

Date weighed	Number of bream per pound
March 24 when stocked............	78
June 15.......................	6
July 13.......................	6
August 13.....................	8
November 30...................	8

The bream grew rapidly until spawning time, and by June 15,000 small bream were found in the pond. The food consumed by the young bream reduced the amount available for the older bream, and instead of growing, they became smaller in size. Ponds stocked with only bream produced few legal-size fish in 5 to 10 years.
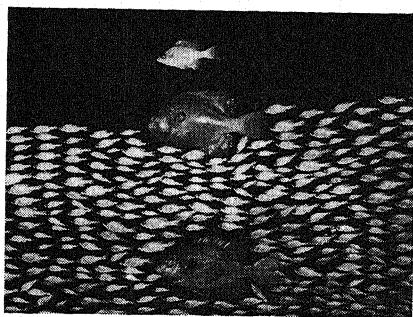
FIG. 2.—Ponds stocked with bream only produce few legal size fish (9). (Courtesy Alabama Agricultural Experiment Station.)

Crappie (white perch) have been found unsatisfactory for keeping blue gill bream down to a desirable number (8). The feeding habits of young crappie are almost like those of bream. Large crappie consume fish mostly, but they may eat insects also. Small crappie eat insects largely. There is no reason for not putting a few crappie in a pond, but they will not take the place of bass for thinning out bream.

Stocking ponds with adult blue gill bream, white crappie, yellow
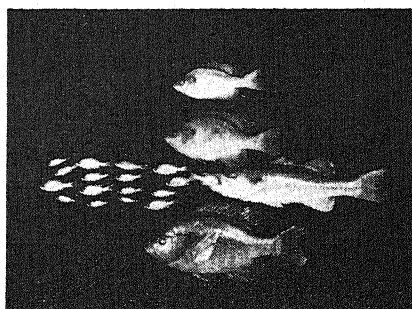
FIG. 3.—Where ponds are properly stocked, bass eat most of the bream, and the others grow satisfactorily (9). (Courtesy Alabama Agricultural Experiment Station.)

bullheads, and large mouth bass was found unsatisfactory (8) in Alabama:

Legal size fish added December 1936	Number of fish December 1939	
	Small fish	Legal size
10 blue gill bream....................	20,615	28
10 crappie..........................	3,848	8
10 bass............................	None	9
10 yellow bullheads.................	668	212[1]

[1] One-half pound or larger.

The pond was 1.8 acres in size. The large number of small bream, crappie, and yellow bullheads consumed all of the available food, and they did not have sufficient food to grow. The competition for food was so great that the small bass could not survive.

Bream and crappie may be established in a pond by placing a few pair of adult fish in a pond, but it is essential to put the desired number of bass in the pond at the time of stocking. The bass may be placed in the pool as fingerlings at the time the adult bream and crappie are put in. Using the recommended number of fingerling bream and bass should always be satisfactory; attempts to use any adult fish may be unsatisfactory.

When ponds have been improperly stocked, and they are overstocked with bream, which are small and thin, and no bass are present, good fishing may be obtained by putting in 100 fingerling large mouth black bass per acre. If bass are present, fertilization of the pond to increase the food will enable the bass to reproduce, and a proper

balance between bream and bass will result (9). Where most of the bream are large, and the bass are small and thin, there are too few bream in the pond. The condition can be corrected by reducing the bass by fishing and seining, after which the pond should be fertilized to increase the food supply.

Draining old pools (9) to remove the large undesirable fish, and restocking with the correct numbers of small fish will improve fishing.

Golden shiners are good fish for bass to eat, but they are no better than bream (9). They should not be put in ponds, for they reduce the quantity of bream which may be produced. The weight of golden shiners was found to be more than the weight of legal-size bream taken by fishing and draining a pond in Alabama.

Channel catfish and yellow bullheads do not thrive in small ponds which are well stocked with bass (9).

Top water minnows may be added to ponds to control mosquitoes.

The production of 1500 pounds of fish per acre per year by the common striped salt-water mullet (Mugil cephalus) has been reported where they were grown in fresh water ponds in North Carolina (1). The small fish were taken from salt water, and grown in an unfertilized pond. Much higher yields were suggested as a possibility where ponds are fertilized.

The salt water mullet was reported to eat the plankton directly instead of insects as bream eat, and small fish as bass eat. If the food habits of the fish in question have been properly described, the suggested production of 5,000 pounds of mullet per acre appears to be reasonable.

The practicability of growing salt-water mullet in fresh water may not be well established; however, it is interesting to note that much higher yields of fish were produced with these fish which eat plankton directly than are produced by those types which eat insects or small fish.

Small bream and any other fish should be legal bait. Many states have laws which prohibit the use of game fish for bait, and as a result inedible fish are used. Inedible fish used for bait is a source of inedible stock in fishing waters when they are released by chance. The presence of inedible fish in waters reduces the amount of edible fish which can be supported by the available food. It has been shown that forage fish, like blue gill bream, produce very large numbers of young, most of which are normally consumed by bass and other fish eating fish. If bream were used, bait would not be a source of undesirable fish. It would be impracticable to attempt to get sufficient bream for bait

on a fishing trip except where water is overstocked. Bream could be grown in ponds for bait. It appears that bream and other edible forage fish should be legal bait, and there are very good reasons why the use of inedible fish should be illegal.

Inability to catch sufficient small bass to influence the stock in fishing waters suggests that there is no basis for their use as bait being illegal.

Closed fishing seasons, and legal size limits have no scientific basis. Few fish can be caught except when food is limited. Most of the small fish can not reach maturity, due to shortage of food. When under-size fish are caught many of them die from injuries when put back into the water. Removing the ones which would live if put back would increase the food for those which remain in the water. It appears that the wishes of the fisherman should determine the time of fishing and the size of fish taken rather than laws.

Since the reproduction and growth of fish is such that they adjust themselves to the food supply available, there probably is no scientific basis for putting small fish in streams or removing fish from streams which are drying up to other streams or lakes. Where waters have once been properly stocked they usually contain all of the fish they will support without increasing the food supply. The addition of more fish reduces the food for those present.

Weeds and brush furnish protection to young fish from bass, which may enable bream to increase in numbers to the point where the pond is overstocked (9) and young bass are not able to survive the competition of the bream. Ponds should be free from weeds and brush so that bass can catch most of the bream. Spatterdock, water-

FIG. 4.—Spatterdock, waterlilies, and other similar weeds should be removed from ponds (9). (Courtesy Alabama Agricultural Experiment Station.)

lilies, lotus, and watershield can be destroyed by cutting the leaves with a scythe in June and every 2 to 3 weeks thereafter until no new growth appears. Water hyacinths can be raked out of a pond. Bullrushes can be controlled by pulling them up or by removing the leaves frequently. Where ponds are built on wooded valleys, they should be cleared, and the logs and brush should be burned just as carefully as if the land were being put into cultivation. If a pond is built in a wooded valley which fills up with brush as the timber falls, the bream

FIG. 5.—Submerged weeds should be removed from ponds (9). (Courtesy Alabama Agricultural Experiment Station.)

are protected from the bass to such an extent that the pond becomes filled with little bream, which never get large enough to catch. The numerous small bream compete with the fingerling bass for food, and the small bass do not survive. Under these conditions the pond is filled with bream too small to eat, and it has a very few big bass which are too fat to bite.

From 3,500 to 5,000 "red worms" for fishing (10) may be produced in a wash tub which is two feet in diameter and 10 inches deep. Only clay soil is suited for growing earth worms, and it should be three-fourths soil and one-fourth decaying leaves or straw. The food used is one pound of corn meal and one-half pound of cheap lard mixed with the top two inches of soil every two weeks, at which time sufficient water (usually one quart) is added. One hundred large red worms should be added, and the top of the tub should be covered with a burlap bag to keep the soil from drying out. The fishing worms should be ready for use in less than 6 months. The tubs should be painted on the inside with asphalt or good paint to prevent rusting. The tub should be put in a cool place. If small greyish-white mites become numerous in the tub, they can be controlled by dusting the top of the soil lightly with sulphur.

Crickets may be grown successfully for bait (3). A six-inch layer of fine sand moistened until it feels damp is placed in suitable containers for the eggs to be laid in. Since young crickets require dry sand to live on, no additional water is applied.

A saucer containing chicken laying mash, and a drinking fountain made from a fruit jar inverted in a saucer are placed on the sand. Cotton is put in the saucer to prevent young crickets from drowning. A five inch layer of wood excelsior is placed around the food and water containers to protect the young crickets and to furnish more surface for them to rest on.

Small containers should be stocked with 20 to 30 mature crickets, and larger containers with 10 or more per square foot. During the first two weeks dead crickets should be removed to reduce diseases.

A crop of 400 crickets may be raised in a 24-inch can every three months. Two pounds of laying mash is required per 100 crickets. The growth of crickets is most rapid between 80° and 90° F., and practically stops below 70°F. Dusting around the cans with suitable insect powder will keep ants away. As many as four crops may be raised without cleaning the cans; however, it is desirable to clean them after one or two crops.

SUMMARY AND CONCLUSIONS

The data from Alabama on fertilizing and stocking fishing ponds were reviewed. The following recommendations were drawn from the data presented:

1. Number of fish per acre

   unfertilized ponds:
   400 fingerling blue gill bream
   30 large mouth black bass

   fertilized ponds:
   1500 blue gill bream
   100 large mouth black bass

2. Fertilizer per acre
   40 pounds of sulphate of ammonia
   50 pounds of superphosphate (20%)
   5 pounds of muriate of potash
   15 pounds of lime or 30 pounds of basic slag,

   Other fertilizers may be used—see page 407.

Apply the above fertilizers at weekly intervals for 3 weeks after

danger of floods in March, and at monthly intervals thereafter until October.

3. Keep all brush out of ponds.
4. Drain and restock poorly stocked ponds.
5. Control water moss or grass in ponds by winter and early spring fertilization. Control other weeds by cutting or pulling.
6. Fishing worms may be produced in a tub or barrel on a ration of corn meal and lard.
7. Crickets may be raised on chicken laying mash.

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(19)

The Effect of Fertilizers on the Yield and Feeding Value of Hay and Pasture Crops

Both plants and animals require plant nutrients.

Successful livestock enterprises are dependent upon the length of the grazing season, and upon the plant nutrient content of hay and pasture crops. The number of livestock which may be kept on an area is limited by the yield of hay and pasture crops. The quality of pasture crops grazed by animals is usually much higher than that of hay crops from similar land. The cost of hay for wintering cattle is several times the cost of pasture for a similar period. As an illustration, the cost of pasturing a cow may vary from $0.50 to $1.00 per head per month where the cost of winter feed varies from $5.00 to $10.00 per head per month. Successful production of livestock is, therefore, tied up closely with the length of the grazing period.

In most states there are fertile soils which produce livestock successfully and poor soils which do not. The application of plant nutrients in the form of commercial fertilizers to poor soils may increase the yield and nutrient content of hay and pasture crops and lengthen the grazing season so that these soils also produce livestock successfully. The plant nutrients which may be deficient in the soil for plant growth and which may be deficient in hay and pasture crops for animal growth are nitrogen, phosphorus, lime (calcium), copper and magnesium. In a few areas, cobalt is too low in hay and pasture crops for animal growth; cobalt has also been found essential for plant growth.

Where hay and pasture crops are low in phosphorus, broken bones, knocked down hip joints, and slipped horns in cattle are frequent. Cows suffering from a deficiency of phosphorus chew leather and decaying bones. High producing dairy cows often have milk fever and other trouble when they are eating hay and pasture crops low in

lime. Lime (calcium gluconate) is used in the treatment of milk fever. Similar trouble may be experienced by feeding too much cottonseed meal, which is high in phosphorus, without feeding lime. Sows which have suckling pigs often get down in the hind quarters when the feed contains too little lime. Forages may contain toxic quantities of selenium, and potassium nitrate occasionally in dry climates.

The application of superphosphate to seeded pastures in Australia (26)[1] has produced outstanding results (Table 1). The soil on which

Table 1.—THE EFFECT OF SUPERPHOSPHATE ON THE CARRYING CAPACITY OF PASTURES.

Pounds 45% superphosphate per acre	Sheep carried per acre, 8-year average
None	1.05
45	3.36
90	4.74
180	5.35

the test was conducted was fertile except for an extreme deficiency of phosphorus. The application of superphosphate increased the number of sheep grazed per acre up to five times the number carried without superphosphate. Such outstanding results are not obtained generally, but they illustrate the occurrence of an extreme deficiency of phosphate for pasture production.

Livestock grazing on soils which are low in lime or phosphate pick out areas on which these fertilizers have been applied and graze them more closely (5) than the surrounding unfertilized areas (Table 2).

Table 2.—THE EFFECT OF SUPERPHOSPHATE AND NITRATE OF SODA ON THE YIELD AND QUALITY OF PASTURE GRASSES FOUR YEARS AVERAGE.

Treatment pounds per acre	Yield—pounds dry matter per acre	Percent of growth grazed
None..................................	3,236	76
400 pounds superphosphate............	6,194	94
250 pounds nitrate of soda............	3,891	60

Without fertilizer treatment only 76 per cent of the plants grown were eaten by livestock, while 94 per cent were consumed where superphosphate was applied. The application of nitrate of soda reduced the forage eaten to 60 per cent of that produced. The data show that

[1]Numbers in parenthesis refer to the source of information, page 444.

cattle actually consumed more forage from the unfertilized area than from the area receiving nitrate of soda. Superphosphate increased the yield, to a large extent, by increasing the growth of desirable clovers, while nitrate of soda increased the percentage of undesirable plants.

The effect of lime and superphosphate on the palatability of forage furnishes an excellent opportunity for demonstrating the need for applying them. If strips were fertilized with (a) superphosphate, (b) lime, and (c) lime and superphosphate, the need for these fertilizers would be indicated by the grazing of the animals. They will graze the fertilized plots more often and more closely if the fertilizers have a marked beneficial effect on the forage produced.

The preference of livestock for forage receiving superphosphate in the above experiments may be related to its lime, phosphate, and protein content:

Treatment pounds per acre	Chemical analysis (4-year average)		
	Lime	Phosphate	Protein
	Percent	Percent	Percent
None.....................	1.34	0.32	9.5
400 pounds superphosphate....	2.13	0.53	11.9

Superphosphate increased the lime and phosphate content of the forage by more than 50 per cent, and increased the protein content significantly.

Preference of cattle for hay from fertilized areas is shown by experience in Missouri (1). In 1936, 4 acres was fertilized with different fertilizers at a rate which usually did not exceed 300 pounds per acre. No fertilizer was used during the following 9 years. Hay from the 4 fertilized acres was stacked with that from 21 acres of unfertilized land, and hay from three unfertilized areas of 25 acres each was used to make three additional stacks. In October 200 head of cattle were turned into the field to eat the unharvested grass and the stacked hay.

Even though the stack containing hay from 4 acres of fertilized land and 21 acres of unfertilized land was farther from salt and water, the cattle ate this stack before starting on those which contained no hay from fertilized land. Without additional fertilizer treatment the cattle showed the same preference for 8 years. On the 9th year cattle showed no preference for hay from the 25 acres including the 4 acres which was fertilized, but they preferred to graze where the fertilizers
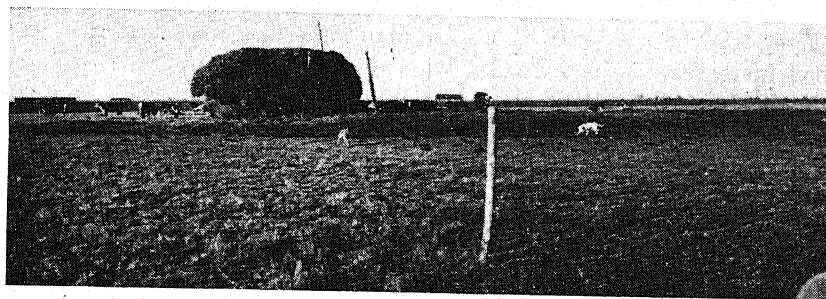
Fig. 1.—Cattle in 1943 were still choosing the stack containing some hay from soils fertilized in 1936. (Courtesy Missouri Agricultural Experiment Station.)
A. "View of the four haystacks each containing hay from 25 acres. The one in the foreground contained some hay from fertilized soils."
B. "Cattle in process of taking the part of the stack containing some hay from fertilized soil and leaving the end of the stack in which there was none of such hay."
C. & D. "The end of the stack left by the cattle when they were going as readily to the other stacks of hay from unfertilized soil as to this remnant."

had been applied 9 years previously. The effect of the fertilizers on the palatability of hay and grass lasted for 8 or 9 years after application.

The effect of one application of superphosphate on the yield of pasture grasses and clovers on the succeeding years (5) is shown by data in Table 3. One application of 400 pounds of superphosphate

Table 3.—THE EFFECT OF ONE APPLICATION AND FOUR ANNUAL APPLICATIONS OF SUPERPHOSPHATE ON THE YIELD OF PASTURE GRASSES AND CLOVERS.

Treatment per acre	Pounds dry matter per acre				
	1937	1938	1939	1940	Total
	Actual yield				
None..........................	1,763	3,912	3,578	3,691	12,944
400 lb. superphosphate in 1937....	3,097	6,325	4,400	4,495	17,317
400 lb. superphosphate annually...	3,097	8,787	5,769	7,121	24,774
	Increase in yield over no treatment				
400 lb. superphosphate in 1937....	1,334	2,413	822	804	5,373
400 lb. superphosphate annually...	1,334	4,875	2,191	3,430	11,830

almost doubled the yield of pasture plants the first year, and it gave good increases on the following three years. The application of 400 pounds of superphosphate annually doubled the yield of pasture plants. On the basis of the above data, liberal applications of superphosphate to pastures which need phosphate during periods of high prices for livestock may produce good profits, and the residual effect of the

FIG. 2 —Left—One acre of improved pasture per cow maintained cows in a thrifty condition, and a 100 percent calf crop was produced. Right—Cows were unthrifty and did not produce a full calf crop on 2 to 4 acres of unimproved pasture per cow. (Courtesy Georgia Agricultural Experiment Station.)

fertilizer may increase the income considerably during periods of low livestock prices.

The effect of pasture fertilization on the production of milk and butterfat was studied by the Louisiana Agricultural Experiment Station (16) (Table 4). The fertilizer applied was 200 pounds of super-

Table 4.—THE EFFECT OF FERTILIZING PASTURES ON THE PRODUCTION OF MILK IN LOUISIANA.

	1932		1933	
	Not Fertilized	*Fertilized*	*Not Fertilized*	*Fertilized*
Cow days per acre................	162	324	139	220
4% butterfat milk—pounds per acre	3,045	6,423	3,038	4,937
Butterfat—pounds per acre........	130	270	129	219
Grain—fed in proportion to milk yield.......................	981	2,086	926	1,402
Cost of grain...................	$8.50	$18.09	$9.82	$14.70
Returns over feed at 30¢ for butterfat........................	$30.53	$62.83	$28.95	$51.05
Increase for fertilizer............	....	$32.30	....	$22.10
Cost of fertilizer...............	....	$ 8.00	....	$ 8.00
Profit........................	....	$24.30	....	$14.10

phosphate and 200 pounds of nitrate of soda, which cost approximately $8.00 per acre. The data show that the use of fertilizer was highly profitable. The interpretation of the data is complicated by more grain being fed to the cows on the fertilized pasture. The use of superphosphate alone may have produced similar increases in milk production.

The application of nitrogenous fertilizers to white clover[1] and grass pasture in New York (15) was not beneficial (Table 5). The pasture received ample lime, phosphate and potash. The effect of nitrogenous fertilizer on white clover and grass pasture was to increase the grasses at the expense of clover without influencing the yield significantly. The grasses had the same protein content with or without nitrogen fertilization, which suggests that clover supplied nitrogen just as well as fertilizer. These data suggest that it is more desirable to apply phosphate, lime, and potash where these fertilizers are necessary for the establishment and maintenance of white clover than to apply nitrogenous fertilizers.

The data illustrated in Figure 3 from North Carolina **show that both lime and superphosphate** are necessary for good yields of pasture

[1]White clover includes wild white, white Dutch, and Ladino clovers.
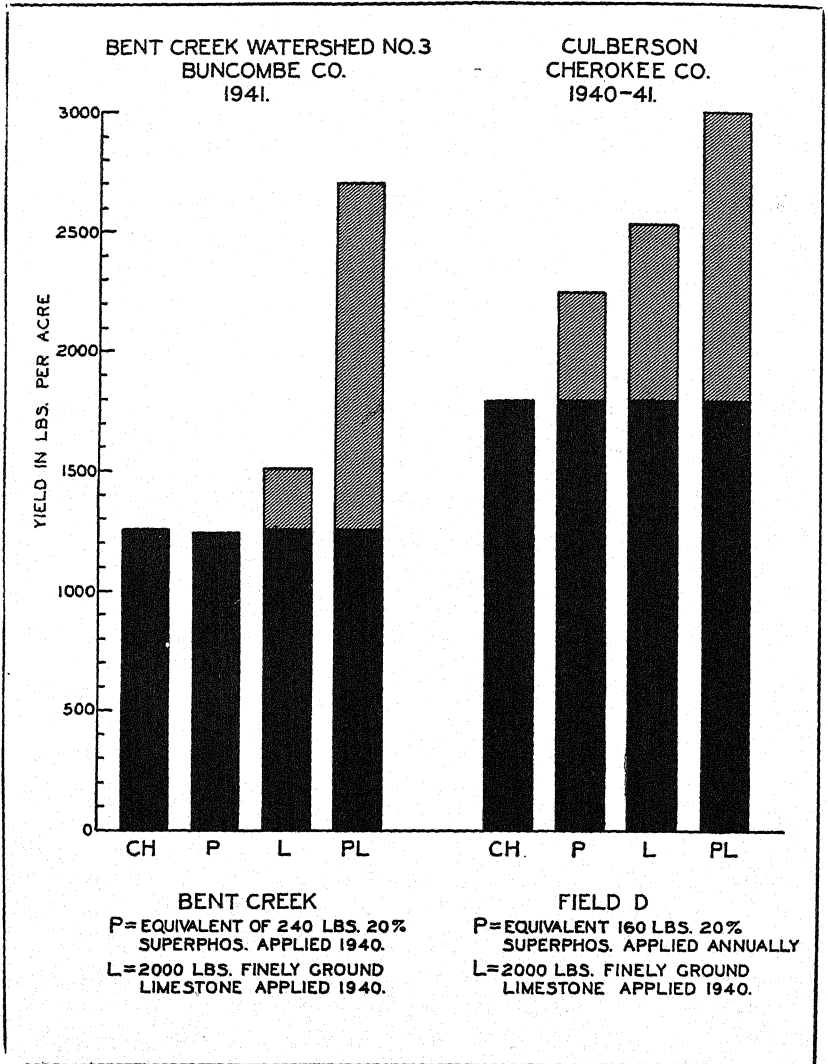
FIG. 3.—Both lime and phosphate are needed on many pasture soils (31). (Cut courtesy North Carolina Agricultural Experiment Station.)

grasses on some soils, while response to either lime or superphosphate may be obtained on some soils (31). On the Bent Creek soil no response to phosphate was obtained without lime. Where lime was used, superphosphate was much more efficient than on unlimed soil.

The effect of phosphorus content of hays on their feeding value

Table 5.—THE EFFECT OF NITROGENOUS FERTILIZERS ON THE YIELD AND COMPOSITION OF GRASS AND WHITE CLOVER PASTURE IN NEW YORK.

Treatment per acre	Estimated cost	Total forage			Grass		Clovers	
		Yield lbs. dry matter	Protein		Percent of total	Protein percent	Percent of total	Protein percent
			Percent	Pounds				
200 pounds cyanamid.............	$4.00	6,210	29	1,801	59	27	41	36
218 pounds sulphate of ammonia......	4.36	6,341	30	1,902	58	27	42	36
288 pounds nitrate of soda..........	5.76	6,699	31	2,077	55	27	45	37
None.............	....	6,276	31	1,946	49	27	51	37

has been determined in a large number of tests conducted by the Tennessee Experiment Station (30). The hays were selected for differences in phosphorus content without regard to the soils on which they were grown or to the fertilizer treatment. Rats were used in the experiments. The feeds were so balanced that they contained the same amounts of lime, phosphate, protein, fat, fiber, and carbohydrates, etc. The following data are typical of the results obtained:

Phosphate content of red clover hay	Relative increase in weight	Phosphate recovered
0.27%	12	26%
0.71%	40	56%

Three times as much increase in weight of rats was obtained from the high-phosphate hay as from the low-phosphate hay. Twice as much phosphate was digested from the high-phosphate hay as from the low-phosphate hay. Since the same amount of phosphate was fed to the rats from both the low-phosphate and the high-phosphate hays, the data suggest that the availability of the phosphate in the low- and in the high-phosphate hays was responsible for the results obtained.

Samples of the two hays were burned, and the ash was fed to rats in similar experiments. The data are as follows:

Source of ash	Relative increase in weight	Phosphate recovered
Low phosphate hay...........	5	34%
High phosphate hay...........	22	63%

The growth and the per cent of the phosphorus recovered when rats were fed ash from the high- and the low-phosphate hays were similar to that obtained when they were fed the hays, which suggests that there was something in the low phosphate hays and in the ash from the low phosphate hays which interfered with the utilization of the phosphorus present.

The above data on the feeding value of low-phosphorus and high-phosphorus hays are very interesting. As was pointed out, the above hays were selected on the basis of their phosphorus content without regard to the soils on which they were grown. Even though the data show a marked difference in the feeding value of the hays, it is not logical to conclude that the application of phosphorus to soils low in this element would produce similar increases in the feeding value of hays. Much more information is needed on this subject.

The iron and aluminum contents of the hays and ashes used in the above experiments was determined. The low phosphate hay contained sufficient iron and aluminum to convert five-sixths of the phosphorus into iron and aluminum phosphates, which would leave only one-sixth of the phosphorus in other forms. In the case of the high phosphate hays, the iron and aluminum content was sufficient to convert four-sixths of the phosphorus into iron and aluminum phosphates, which would leave two-sixths of the phosphorus in other forms. When the same amount of phosphate was fed to rats in the hays or the ash of the hays of low and high phosphate content, the high phosphate hay or ash contained twice as much phosphorus in forms other than iron and aluminum phosphate, and the rats actually utilized about twice as much phosphate from the high phosphate hay as from the low phosphate hay. However, the rats utilized some phosphate from both hays, which apparently could have been tied up as iron and aluminum phosphates.

The above data on feeding value of hays are comparable to well established facts in soils, which have been studied in more detail. It is well known that the application of lime or phosphate to acid soils reduces the amount of iron and aluminum which come into solution. In fact, poor growth of plants on acid soils has been ascribed, though probably incorrectly, to the toxicity of soluble iron and aluminum. One of the generally accepted benefits for liming acid soils is that lime prevents available phosphate from being converted into less available iron and aluminum phosphates. Liming acid soils reduces the aluminum and iron taken up by plants. The property of lime and phosphate applied to acid soils of making iron and aluminum less available to plants and thereby reducing the amounts of these elements

in feeds may be of as much importance as their effect on the lime or phosphate content of plants, as is indicated by the reduction in the utilization of phosphate produced by iron and aluminum in the hay fed in the above experiments.

The available phosphorus in soils is usually determined in dilute acid extracts of the soil. It has been shown that the amount of available phosphorus in the extract is markedly reduced when the extract stays in contact with the soil an undue length of time, presumably due to the precipitation of the phosphorus as iron and aluminum phosphates. The digestion of food in the stomach of animals is carried on in dilute acid similar to that of soil testing solutions. As the data on the effect of iron and aluminum on the feeding value of hays suggest, it appears logical that iron and aluminum in foods precipitate phosphate brought into solution in the stomach, as they do in soils and dilute acid extracts of soils, and cause it to pass out through the digestive tract, thereby reducing the amount of phosphorus utilized by the animal.

The application of fertilizers needed by plants does not always result in a measurable change in the chemical composition of crops as is shown by data (2) in Table 6. Phosphate alone had no influence

Table 6.—THE EFFECT OF FERTILIZERS ON THE CHEMICAL COMPOSITION
OF PASTURE GRASSES.

Soil treatment	Yield of hay, pounds per acre	Chemical composition		
		Lime	Phosphate	Protein
		Percent	Percent	Percent
None.....................	762	2.33	0.44	11.2
Phosphate.................	800	2.45	0.46	11.3
Lime and phosphate..........	1,394	2.35	0.44	13.1

on the yield, or on the lime, phosphate, and protein content of the hay. Lime and phosphate increased the yield and protein content of the hay, but had no influence on its lime or phosphate content.

The application of lime increased the feeding value of lespedeza hay (2) without changing its chemical composition significantly in Missouri:

Treatment	Yield of hay pounds per acre	Weight of sheep produced
Phosphate only..............	3,000	211
Lime and phosphate..........	3,812	302

There was no difference in the protein and phosphate content of the hays. The hay from the unlimed soil contained 2.8% lime and that from limed soil contained 3.3% lime. The application of lime increased the yield of hay 27% and increased the feeding value of the hay sufficiently that hay from the limed soil produced 43% more weight in sheep.

The effect of superphosphate and lime on the feeding value of lespedeza hay in Missouri (2) is shown by data in Table 7. The appli-

Table 7.—THE EFFECT OF SUPERPHOSPHATE AND LIME ON THE FEEDING VALUE OF LESPEDEZA.

Year	Soil treatment		
	None	Superphosphate	Superphosphate and lime
	Hay required to produce 1 lb. gain in lamb weight		
1939		29.2	19.4
1940		14.2	12.6
1941	12.7	9.7	7.6
	Grain supplement per lb. gain in weight		
1939		6.8	4.5
1940		3.5	3.0
1941	4.3	3.5	2.5

cation of lime in addition to superphosphate increased the 3-year average yield of lespedeza hay from 2,120 to 2,770 pounds per acre, or 26%. The 2,120 pounds of hay from land treated with superphosphate produced only 136 pounds gain in lamb weight, while the 2,770 pounds of hay from land treated with lime in addition to superphosphate produced 227 pounds gain in lamb weight, which is an increase of 67%.

The application of lime or superphosphate reduced the amount of hay and grain supplement required to produce one pound gain in weight of lambs.

The effect of fertilizer treatment on the yield and feeding value of Korean lespedeza hay is shown by data (25) in Table 8 from Missouri. The treatment was lime and superphosphate, and potash where needed. The treatment produced substantial increases in the yield of hay, reduced the amount required to produce a gain of one pound in rabbit weight, both of which increased the amount of meat produced from a given acreage.

Where potash was deficient for plant growth the application of
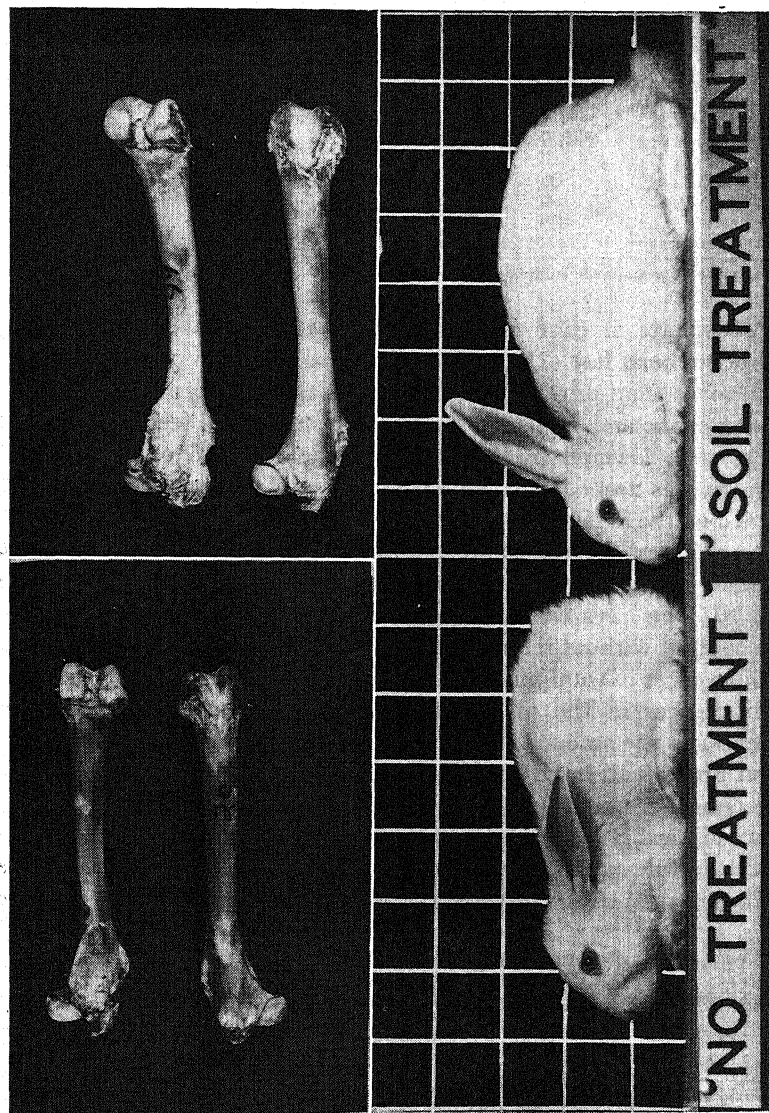
FIG. 4.—The growth of rabbits improved and their bones were larger when the forage was from fertilized soil. (Courtesy Missouri Agricultural Experiment Station.)

Table 8.—The Effect of Fertilizer Treatment on the Yield and Feeding Value of Hay.

Soil Series	Yield of hay, lbs. per acre		Hay consumed per lb. of gain*		Yield as pounds of gain per acre*	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
Putnam..........	2,180	3,800	13.2	9.4	116	254
Clarksville.......	520	2,020	7.9	5.5	39	233
Eldon...........	2,500	4,500	6.8	5.9	241	471
Lintonia.........	2,250	2,800	7.0	5.1	180	316
Grundy..........	2,400	3,760	7.4	6.5	180	303

*Assuming all gains made from hay.

superphosphate or lime and superphosphate decreased the feeding value of soybean hay (25) (Table 9). The application of 15 pounds of potash more than offset the reduced feeding value produced by lime and phosphate and increased the yield of hay. The feeding value of timothy was lowered by nitrogen treatment where other fertilizer treatment was needed (25). These data suggest that much information is needed on the feeding value of forages as influenced by soil treatment.

The effect of the phosphate content of hays on their feeding value for calves is shown by the data from Tennessee (14) presented in Table 10. The hays were selected for high-phosphate and low-phosphate content without reference to soil or previous fertilizer treatment. The differences in total phosphate content of the hays may not indicate the differences in the phosphate available to the animals, due to differences in the amount of iron and aluminum which may have been present and which have been shown (above) to alter the availability of the phosphorus present. As the data stand, the high phosphate hays were considerably better feeds in two of the tests, and in one of the tests the low phosphate hay was more efficient than the high phosphate hay. In the latter case, the reversal was attributed to the low phosphate

Table 9.—The Effect of Unbalanced Soil Treatment on the Yield and Feeding Value of Soybean Hay.

Treatment	Yield—lbs. hay per acre	Gain in weight of rabbits[1]
None......................	2,780	296
150 lbs. 0-20-0.................	2,500	229
150 lbs. 0-20-10...............	3,800	352
150 lbs. 0-20-0 + lime..........	2,940	88
150 lbs. 0-20-10 + lime.........	3,800	363

[1]Average gain in grams per rabbit in 49 days.

hay being of better quality, which is partially borne out by its higher protein content. In one test, feeding extra phosphate as dicalcium phosphate largely overcame the inferiority of the low-phosphate hay.

The percent of clover in hay on phosphated land was three times as high as that on untreated land in Tennessee (14). Phosphate is applied to forage crops to increase the phosphate content of the forage, to lengthen the grazing season, and to increase the yield. An increase

Table 10.—THE EFFECT OF THE PHOSPHORUS CONTENT OF RED CLOVER HAYS ON THE FEEDING VALUE.

Item	1939-'40		1940-'41		1942-'43	
	Low Phosphate	High Phosphate	Low Phosphate	High Phosphate	Low Phosphate	High Phosphate
	Chemical analysis—percent					
Phosphate........	0.27	0.71	0.37	0.55	0.23	0.46
Protein..........	10.6	10.2	12.1	10.9	9.4	14.6
	Gain in weight—pounds per calf					
Feed only........	79	124	173	117	36	102
Feed plus extra phosphate......	....	....	....	....	90	109
	Length of test					
Days............	196		252		168	

in yield or an increase in the length of the grazing season due to the application of phosphate is easily recognized. An increase in phosphate content of particular forage plants is not always obtained. Instead of increasing the phosphate content of particular forage plants, an application of phosphate fertilizer is more likely to increase the total yield and increase the percentage of phosphate-loving plants, like clover, relative to the grasses which normally contain less phosphorus.

The application of superphosphate to soil very low in phosphorus will increase the phosphate content of the plants a small amount. However, it is improbable that economical applications of phosphate to soils low in phosphorus will increase the phosphate content of plants to that of the phosphate content of plants grown on phosphorus rich soils. It is more improbable that the quality of forage produced on poor soils can be increased to the quality of forage from good hay and pasture lands by economical application of fertilizers.

Fig. 5.—White Clover. No treatment on left. Treated with phosphorus on right. (Courtesy Georgia Agricultural Experiment Station.)

The production of grasses and clovers throughout the growing season is necessary for the most profitable production of livestock. An ideal pasture would produce forage throughout the year; actually the grazing period is much shorter than a year. The length of the grazing period is determined by the kind of pasture plants which are present. In the Middle West and Northeast, Kentucky blue grass and white clover make a reliable combination of pasture plants; in the South and Southeast, white clover, hop clover, lespedeza, Dallis grass and Bermuda grass are the pasture plants commonly used in improved pastures.

The nodule bacteria on the roots of legumes take nitrogen out of the air, which is used by the legume for growth. The residues from the legumes and both the solid and the liquid manure derived from the legumes in pastures supply nitrogen for the associated grasses. The nitrogen supplied in this manner tends to produce a uniform growth of both the legumes and the grasses, and the grazing furnished to livestock is distributed more uniformly through the growing season than when nitrogen is derived from fertilizers. Nitrogenous fertilizers are used rather quickly by pasture grasses, and an overproduction of

grasses which become tough and woody is often obtained from their use. Where commercial nitrogen is used for pastures, it appears necessary to apply small amounts at frequent intervals to maintain uniform production. It is doubtful if the application of commercial nitrogen to pastures will become generally profitable for beef cattle and dairying
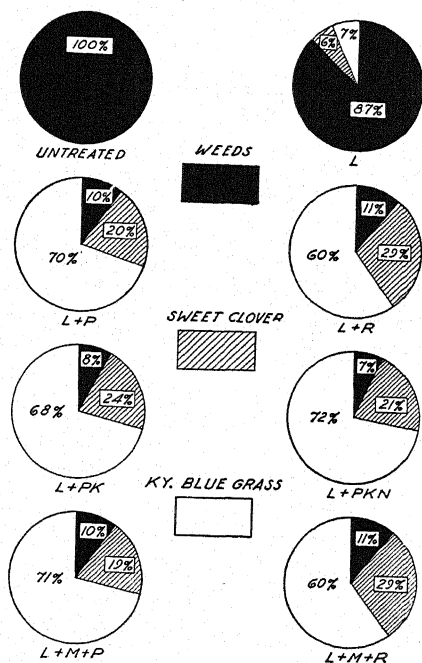
FIG. 6.—Phosphate, potash, and lime enable grass and clover to grow where only weeds grew before (18). L = lime, P = superphosphate, R = rock phosphate, M = manure.

for condenseries, cheese plants, and creameries, due to the low income from these enterprises. It may be highly profitable to apply nitrogen to pastures which have a low clover population where market milk, which brings a relatively high price, is produced. In general it appears most profitable for livestock enterprises to depend upon legumes to supply nitrogen for forage crops.

White clover in combination with grasses makes a good pasture combination throughout most of the improved pasture-producing areas. In the South and Southeast white clover begins growth when the first warm days come in late winter, and it supplies good grazing before the grasses begin to grow, and furnishes nitrogen for the grasses which

follow. The effect of growing white clover on the yield of Kentucky blue grass (15) and on the total yield of forages is shown by the data in Table 11 from New York. The presence of the white clover increased the yield of Kentucky blue grass from 881 to 2,193 pounds per acre, and increased its protein content from 18 to 25%. The total protein in the grass grown with clover was $3\frac{1}{2}$ times as much as that in grass grown alone.

Table 11.—THE EFFECT OF CLOVER ON THE YIELD OF GRASS.

Plant combination	Yield of dry material, pounds per acre	Protein, percent
Grass alone...........................	881	18
Wild white clover alone................	3,072	35
Grass grown with clover...............	2,193	25
Clover grown with grass...............	2,742	35
Total grass and clover...........	4,935	31

The presence of the Kentucky blue grass reduced the yield of the clover from 3,072 to 2,742 pounds per acre, which may be insignificant. The yield of grass and clover grown together was 4,985 pounds of dry material per acre which is six times the yield of grass grown alone.

The above data show the importance of the growth of clovers with grasses for pastures. White clover usually can not be replaced with other clovers if the best pastures are to be produced. Success with this clover is dependent upon a good supply of phosphate and lime in the soil. Pasture soils which are poor must be fertilized so that they will produce good white clover and other legumes if the best pastures are to be produced.

The effect of fertilizers on the carrying capacity and on the beef produced on pastures at the Cotton Branch Experiment Station, Arkansas, (21) is shown by the data (average for 4 to 5 years) reported in Table 12. The pastures contained Bermuda grass, clovers, and lespedeza. Nitrate of soda and 4-10-4 fertilizer produced small increases in yield in comparison to lime and superphosphate. The lime and superphosphate treated pasture produced $17.15 more beef (valued at 7 cents per pound) than was produced without fertilizer. The annual cost of this treatment was approximately $2.00 per acre. These data are particularly interesting because the increases were produced on soil which produced 314 pounds of beef per acre without fertilizer.

The application of superphosphate to pastures at the Arkansas

Table 12.—The Effect of Fertilizers on the Carrying Capacity of Pastures.

Fertilizer treatment per acre	Stock per acre	Pounds of beef per acre	
		Produced	Increase
None...................................	1.86	314	....
100 lb. nitrate of soda....................	1.98	388	74
400 lbs. 4-10-4.........................	2.58	413	99
140 lbs. 20% superphosphate +1 ton lime[1]..	2.52	559	245

[1]Only one application of lime.

Rice Experiment Station (21) increased the production of beef significantly over a 2-year period (Table 13). The value of the increase in beef produced where 120 or 240 pounds of superphosphate was applied per acre (at 7 cents per pound) is more than three times the cost of the fertilizer.

Table 13.—The Effect of Superphosphate on the Production of Beef on Pastures.

Treatment per acre	Stock per acre	Pounds of beef per acre	
		Produced	Increase
None......................................	1.76	228	....
120 pounds 20% superphosphate.........	1.97	306	78
240 pounds 20% superphosphate.........	2.01	360	132

Grasses and clovers from good grazing lands contain more protein, lime, and phosphate than the same plants from poor grazing lands (27). The analyses listed in Table 14 were made on plants from good and from poor grazing lands in Ontario, Canada. The grasses and clovers which came from good pastures contained considerably more protein, lime and phosphate than the same plants from poor pastures. The soil from the good pasture contained more than four times as much available phosphate as that from the poor pasture. Except where the available phosphate in the soil is very low, the application of phosphate to pasture land does not result in a marked increase in the phosphate content of the grasses and clovers; however, a reduction of the iron and aluminum content of the forages may be of more importance than an increase in the phosphate content. The application of phosphate to soils of medium to good phosphate content would probably not increase the phosphate content of most plants; its influences would probably be primarily on the relative amount of grass and clovers and on their growth.

Table 14.—Difference Between the Protein, Lime, and Phosphate Content of Forages from Good and Poor Pasture Land.

Name of plants	Analysis of pasture plants					
	Protein		Lime		Phosphate	
	Kind of pasture					
	Good	Poor	Good	Poor	Good	Poor
	Percent		Percent		Percent	
Red clover.............	16.4	14.9	5.8	4.3	0.46	0.32
Sweet clover............	19.3	11.1	5.4	3.7	0.53	0.26
Trefoil................	18.1	15.8	6.2	4.6	0.57	0.35
Canada blue grass.......	7.6	6.3	1.2	0.8	0.4	0.19
Kentucky blue grass.....	5.6	6.7	1.0	1.2	0.33	0.23
Timothy...............	6.4	6.5	1.1	0.9	0.38	0.24
Red top	7.9	6.3	1.2	0.8	0.42	0.24

That the increase in cattle weight produced by the application of fertilizers may be due almost entirely to the increase in the amount of forage produced is shown by data collected by the Ontario Agricultural Experiment Station (27) on poor grazing land. The application of 300 pounds of 2-12-10 fertilizer per acre increased the carrying capacity of pastures by 50 per cent, and the yield per acre by 61 pounds of beef. Superphosphate alone, at less cost, might have been as effective as the complete fertilizer. The fertilizer had no influence on the lime and protein content of the pasture plants, but increased the phosphate content slightly as is shown by the data reported in Table 15. The average increase in weight per head was 295 pounds on unfertilized pasture and 318 pounds on fertilized pasture, which gives a difference of only 23 pounds per head in favor of the cattle on fertil-

Table 15.—The Effect of Fertilizers on the Phosphate Content of Pasture Grasses

Pasture plant	Phosphate content of plants	
	Fertilized	Unfertilized
	Percent	Percent
Trefoil.........................	0.41	0.34
Canada blue grass...............	0.35	0.23
Kentucky blue grass.............	0.35	0.26
Timothy........................	0.36	0.30
Red top........................	0.39	0.30

ized pasture. Since the difference in weight per head was small, and since the carrying capacity and the yield of beef per acre were increased approximately 50 per cent, it appears that the primary value of the fertilizer was to increase the amount of forage produced without increasing its feeding value.

The effect of superphosphate on the production of beef on limestone soils of Alabama (4) is shown by data in Table 16. The differences

Table 16.—THE EFFECT OF SUPERPHOSPHATE ON THE PRODUCTION OF BEEF ON PASTURES.

Superphosphate per acre[1]	10-year average increase in beef, pounds per acre	Value of beef[2]	Annual cost of fertilizer	Profit
1,200 # every three years.....	166	$11.62	$4.00	$7.62
600 # every three years.....	90	6.30	2.00	4.30
200 # annually............	55	3.85	2.00	1.85
400 # annually...........	121	8.47	4.00	4.47
No treatment......	186	....	....	....

[1]16% superphosphate.
[2]Beef was valued at 7 cents per pound.

between the increases in cattle weight for 1200 and 600 pounds of superphosphate every three years as compared to 200 and 400 pounds applied annually are not explainable unless they are due to plot variation. However, the average annual fertilizer cost of $3.00 per acre increased the cattle weight produced 108 pounds per acre each year. The value of 108 pounds gain in steer weight at 7 cents is $7.56. Subtracting the cost of the fertilizer ($3.00) leaves a profit of $4.56 per acre.

The unfertilized pasture produced 186 pounds of beef valued at $13.02. On the basis of these data the income from 3 acres of pasture on which $9.00 worth of phosphate is applied is approximately equal to that of 4 acres of unfertilized pasture. In this case the cost of additional land and the cost of maintaining pastures as compared to fertilizers to produce the same income should be considered in determining the means of increasing the income.

The increase in the yield of beef due to the application of superphosphate in the Alabama experiments was produced largely in April and May (Fig. 7, 8). The primary influence of the superphosphate was to increase the spring clovers. The number of cattle were varied in the experimental work so that the pastures were fully stocked and not over stocked. Farmers are not generally in a position to vary the number of
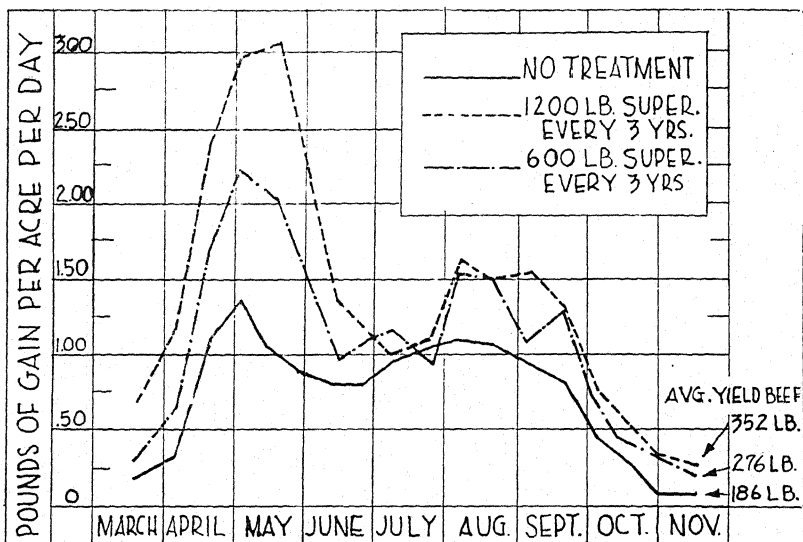
FIG. 7.—Seasonal distribution of gain from pasture, 10-year average, 1933-42 (4). (Cut courtesy American Society of Agronomy.)
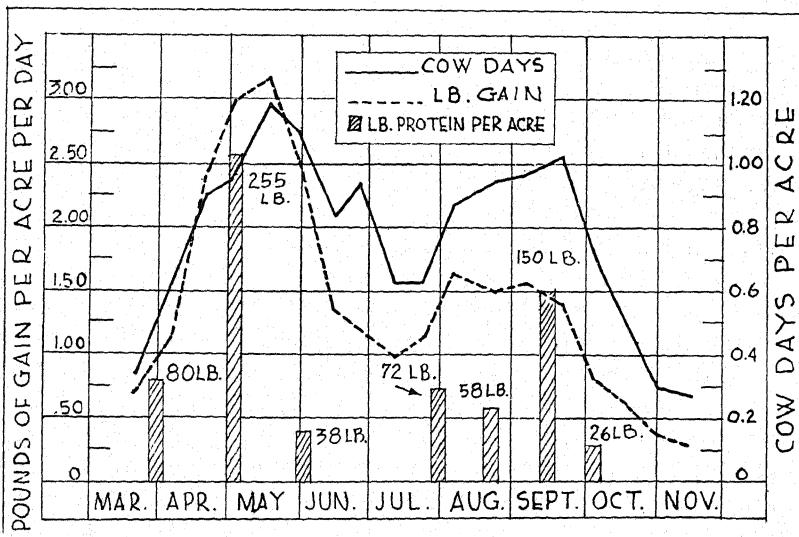
FIG. 8.—Comparison of seasonal distribution of gain and carrying capacity on Black Belt pastures receiving 1,200 pounds of superphosphate every 3 years, 10-year period, 1933-42 (4). (Cut courtesy American Society of Agronomy.)

cattle so that both under-grazing and over-grazing are avoided. There-fore, under farming conditions, where the primary influence of super-phosphate is on the growth of spring clovers its use is questionable unless supplementary grazing is provided, or surplus forage is harvested for winter feed.

Five hundred and fifty-nine pounds gain in steer weight was pro-duced on a white clover and carpet grass pasture (in 1942) which was fertilized with phosphorus, potash, and lime; 605 pounds gain in steer weight was produced in 1943 (Florida) (6). Comparable carpet grass pasture which received 30 or 32 pounds of nitrogen in addition to lime, phosphorus, and potash produced only 172 and 107 pounds gain in weight for the two years. White clover was much more effective than 30 or 32 pounds of nitrogen for the production of forage.

The high gain in steer weights was made by adjusting the cattle to the grass so that the pastures were fully stocked but not over-stocked. Since most farmers do not adjust the cattle to the grass, similar gains would not be expected unless supplementary grazing were provided during periods of low pasture production so that full use of the pasture forage could be obtained.

Supplementary pastures are necessary where permanent pastures are to be grazed to their seasonal carrying capacity, due to a lapse in the carrying capacity between the time early clovers mature and the grasses come in, and to drouths, particularly in the Southeast. The Alabama Experiment Station has observed that the extra stimulus given the early clovers by phosphate causes them to make very lux-uriant growth, which retards the development of the grasses, and a greater break in the carrying capacity comes on fertilized than on unfertilized pastures. Where supplementary pastures are not provided to tide the cattle over these periods of low grass production, losses in weight will result, which need to be regained at a later date.

The Alabama Experiment Station has observed that 25 per cent of the two-year old steers are finished by the time the early clovers disappear (3). If the pasture is stocked to its approximate carrying capacity, and the finished cattle are sold when the clovers disappear, less supplementary pasture is needed, and the pasture will more nearly supply the grazing necessary for the remaining cattle. If supplementary pastures are not provided, and finished cattle are not moved early, the pastures must be understocked in the spring, and considerable early clovers and grasses will go to waste unless they are cut for hay. Most any of the summer hay crops may be used for supplementary pastures.

A lespedeza-small grain rotation may be used for supplementary pastures when the early clovers disappear (11). On land which normally produces 25 to 30 bushels of corn per acre in Missouri, an average of 24 bushels of wheat was produced over a three-year period, and the lespedeza after the wheat produced 133 pounds of steer weight per acre. The lespedeza, after small grains, comes in at a time of the year when extra grazing is needed to supplement permanent pastures.

The lespedeza-small grain system may be used to supply late fall and early spring grazing. In addition, lespedeza reseeds each year, and the only preparation needed is disking for wheat. The lespedeza supplies some nitrogen for the small grain, and the soil organic matter and nitrogen should be maintained at a reasonably high level in this system.

The Missouri Agricultural Experiment Station found that the lespedeza-small grain annual rotation is one of the best means of establishing blue grass, counting economy. Blue grass comes in where this rotation is maintained for several years.

Burning over native wire grass pastures in January (Florida) trebled the phosphorus and protein and doubled the lime content of the grass growing in March (6).

Data on disking fertilizers into pasture sods are (7, 10, 20) presented in Table 17. One of the most interesting observations is that cutting

Table 17.—THE EFFECT OF CUTTING PASTURE SODS AND PLACEMENT OF FERTILIZER ON THE YIELD OF PASTURAGE IN OHIO, INDIANA, AND MICHIGAN.

Treatment	Yields of pasture grass		
	Ohio[1]	Indiana[2]	Michigan[3]
	Green lbs.	Green lbs.	Dry lbs.
No fertilizer—no cutting................	4,867	10,947	1,137
Surface cut with 4″ drill—no fertilizer......	4,600	8,867[4]	....
Fertilizer applied on surface with 4″ drill...	5,933	14,090	1,899
Fertilizer 2″ deep with 4″ drill...........	5,400	12,275	1,711

[1] 345 pounds of triple superphosphate was used per acre, yields were estimated.
[2] 400 pounds of 4-12-12 fertilizer was used per acre.
[3] 400 pounds of 10-6-4 fertilizer was used per acre.
[4] The surface was cut with an 8″ drill.

the sod with either 4-inch or 8-inch drills had no effect on the yield of forage or reduced it significantly. The application of fertilizer on the surface made greater increases in yield than applications made below the surface with a drill. Based on these data, pasture sods should not be disked after applying fertilizers. The fertilizers applied on the

surface are available to plants during the early spring and during periods of high moisture content when the roots are actively growing in the surface. It has been suggested that the layer of organic matter on the surface of pasture soils and that in the top layer of soil help to maintain applied phosphorus in an available form, and as a result pasture plants recover a higher percentage of the phosphate when applied on the surface than when it is applied below the surface in contact with the mineral soil particles, which tend to make it unavailable. Pastures may need plowing to destroy undesirable plants; they should not be plowed solely for covering fertilizer.

The plant nutrients removed in animal products (England) (24) were reported as follows:

Animal product	Pounds phosphate	Pounds potash
100 gallons of milk...............	2.3	2.0
100 pounds of beef cattle..........	1.8	0.2
100 pounds of sheep.............	1.1	0.2

The average amount of milk produced per acre per year on pasture is probably considerably less than 100 gallons, and less than 100 pounds of increase in weight of cattle is produced per acre; however, improved pastures may produce three times the above amounts.

The small amounts of plant nutrients removed from soil in animal products suggest that the productivity of unfertilized pastures may be almost maintained, provided the liquid and solid manure are distributed uniformly over the land. Unfortunately, a considerable amount of the manure is deposited in shaded areas and around sources of water, which tends to concentrate the plant nutrients in these areas at the expense of other parts of the pasture.

The application of superphosphate to pastures to increase production must be repeated frequently, for much of the phosphate becomes less available with time. Broadcast applications of potash to pastures should not have to be repeated often, due to the fact that potash does not leach out of the soil readily when applied in this manner.

The principle of nitrogen starvation of crops when materials low in nitrogen are turned into the soil is duplicated in the stomachs of cattle, except the nitrogen tied up with carbohydrates in the bodies of bacteria becomes a source of protein for the cattle (13, 22, 28). In the soil, soil microorganisms use the available nitrogen in decomposition of

materials like oat straw, and store it in proteins in their bodies, there-by depriving crops of available nitrogen; in the first stomach of cows, bacteria also use soluble nitrogen in the decomposition of low nitrogen feeds like corn, and no doubt grass hays and silage, and store it in proteins in their bodies, which in turn are used as a source of protein by the animal when the food reaches the fourth stomach and intestines.

The Wisconsin Agricultural Experiment Station (22) found that the use of urea nitrogen with low protein rations for dairy cows gave as good results as linseed meal. There were no significant differences in "milk production, breeding efficiency, calf size, or the weight and appearance" of these cows. It was calculated (22) that 3 pounds of urea costing 10½ cents* and 31 pounds of grain would replace 34 pounds of linseed meal. According to these figures, 1,824 pounds of grain and 177 pounds of urea costing $6.19 would replace 2,000 pounds of linseed meal in the feed. According to the above data when 1,824 pounds of grain and 177 pounds of urea cost less than a ton of linseed meal, it is cheaper to use urea and grain instead of linseed meal. Similar calculations could be made for cottonseed meal. Similar results with urea were obtained in Virginia (13). Ammonia applied to beet pulp was an unsatisfactory source of protein (9).

The feeding value of uramon (urea)-treated silage has been tested by the Mississippi Agricultural Experiment Station (8, 17, 18). Ten pounds of uramon was applied per ton of silage as it was put into the silo (Table 18). Beef cattle were used in the tests, and the rations were essentially maintenance winter rations.

In general the data show some advantages for urea treatment of silage; however, the following points should be taken into considera-tion: (a) The urea-treated silage used in the 1942-43 experiments contained about 50% more carotene than the untreated silage, which was not verified in the 1944-45 experiments, from which a question might be raised concerning comparable silage quality in the 1942-43 test. (b) In the 1944-45 tests "chemical analysis showed that the urea-treated silage contained 10 per cent less moisture. . . ." from which it may be calculated that the cows on urea-treated silage received approx-imately 50% more dry matter from the silage than those on untreated silage. The difference in dry matter fed may have been responsible for the difference in feeding value. (c) The urea-treated silage was more palatable than the untreated silage, and the calves and heifers refused to eat the full allotment of untreated silage, which may have been associated with differences in dry matter or moisture contents.

*Urea at $70.00 per ton.

Even though it appears that urea might possibly have a place in the feed where cattle are wintered largely on grass hays and silages, the data available do not warrant its use.

Superphosphate poisoning of cattle has been observed, at the Mississippi Agricultural Experiment Station, where bags of superphosphate were left in the pasture. The cattle ate enough superphosphate to kill them. Calcium silicate slags, and nitrate-containing fertilizers are also poisonous to livestock.

Table 18.—THE USE OF URAMON (UREA) IN SILAGE.

Year	Animals	Daily ration—pounds				Change in weight, pounds
		Untreated silage	Treated silage	Johnson grass hay	Cottonseed meal	
1942-43.....	Cows	35	..	5	..	0
1942-43.....	Cows	..	35	5	..	47 gain
1943-44.....	Cows	30	..	5	1	4 gain
1943-44.....	Cows	35	..	5	..	75 loss
1943-44.....	Cows	..	35	5	..	21 loss
1944-45.....	Cows	30	..	5	1	9 gain
1944-45.....	Cows	35	..	5	..	99 loss
1944-45.....	Cows	..	35	5	..	13 gain
1943-44.....	Calves	15	..	3	1	37 gain
1943-44.....	Calves	20	..	3	..	21 loss
1943-44.....	Calves	..	20	3	..	2 gain
1944-45.....	Heifers	25	..	5	1	61 gain
1944-45.....	Heifers	30	..	5	..	15 loss
1944-45.....	Heifers	..	30	5	..	42 gain

SUMMARY AND CONCLUSIONS

The data reviewed on the effect of fertilizers on the yield and analysis of forage crops, and on the utilization of the forage by animals show:

1. Lime, or superphosphate, or lime and superphosphate usually produce good increases in the yield of pasture and hay crops where legumes are present.
2. Lime, or superphosphate, or lime and superphosphate applied to soils very low in lime and phosphate increase the amount of protein, lime and phosphate in forages.
3. The increase in the protein, lime, and phosphate content of forages in pasture or hay crops, due to the application of lime or phosphate, may be largely due to an increase in the amount of legumes relative to grasses.

4. The feeding value and palatability of forages from soil receiving lime and phosphate as compared to forages from unfertilized soil may be higher than indicated by chemical analyses.
5. Iron and aluminum in forages reduce the amount of phosphorus obtained from the forage by animals.
6. The reduction of the iron and aluminum content of forages produced by the application of lime and superphosphate to soils may be of more importance than the effect of these fertilizers on the protein, lime and phosphate content of plants involved.
7. Lime, or superphosphate, or both are necessary for success with pasture legumes. These legumes must be present for good pasture production.
8. Emergency pastures during periods of low pasture production are necessary if full utilization of pasturage is to be obtained.
9. Pastures should not be disked or plowed when fertilizers are applied.
10. When cattle are fed urea nitrogen with feeds low in protein, bacteria in the first stomach convert nitrogen and carbohydrates into protein in their bodies, which is used as protein by cattle. This principle appears to offer possibilities for wintering cattle cheaply where cattle are normally wintered on grass hays, silage, or grain straw. However, the data are insufficient to recommend its use at the present time.

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